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AGGREGATE EXTRACTION IN YOLO COUNTY

A Study of Impacts and Management Alternatives

Prepared for

Aggregate Resources Advisory Committee
County of Yolo Planning Department

August 1976

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

Cache Creek
Document
85

ACKNOWLEDGEMENTS

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- Jeffrey A. Gilman (hydrology)
- Dustin Garrow (economics)
- Gordon A. Robilliard (ecology)
- Charles R. Comstock (stream lowering)
- Susan Naughton-Quinlan (geomorphology)

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Section I

INTRODUCTION

Section I

INTRODUCTION

This report summarizes the findings of a study which examined aggregate extraction operations in Yolo County, California; the associated physical, environmental, and socioeconomic impacts of those operations; and potential means of controlling adverse effects through management policies. The study focused on Cache Creek, a stream in northern California which flows southerly and easterly from its origin at Clear Lake to its terminus in the Yolo Bypass (a part of the Sacramento River system). It drains approximately 1150-sq miles, located primarily in Lake and Yolo Counties. Particular attention was directed toward operations and conditions on that reach of Cache Creek which extends between the towns of Capay and Yolo (see Figure 1).

BACKGROUND

Cache Creek's value as a source of high quality aggregates has been recognized for many years. During the early decades of this century, when Yolo County was beginning to develop as an important agricultural producer, aggregate materials from Cache Creek were used widely for the construction of roads, rail beds, and concrete structures. However, up through the early 1950's the extraction operations were diffuse and small in scale compared to today's level of production. Now there are eight aggregate extraction operations on Cache Creek which together remove an estimated 2.7 million tons of aggregate materials per year. All of these operations are centered in two major basins, as shown in Figure 2.

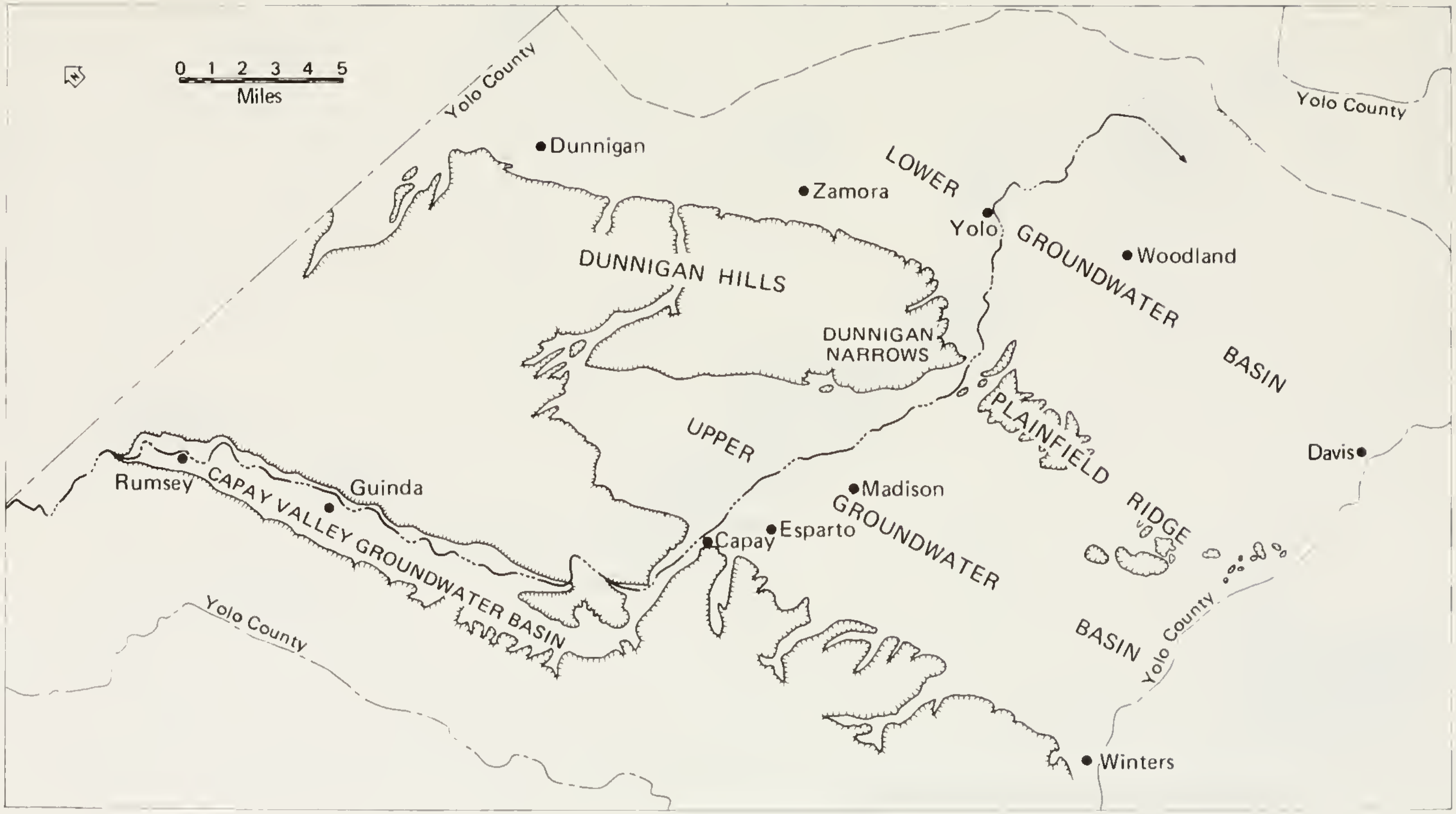

Figure 1. STUDY AREA–GEOGRAPHIC FEATURES

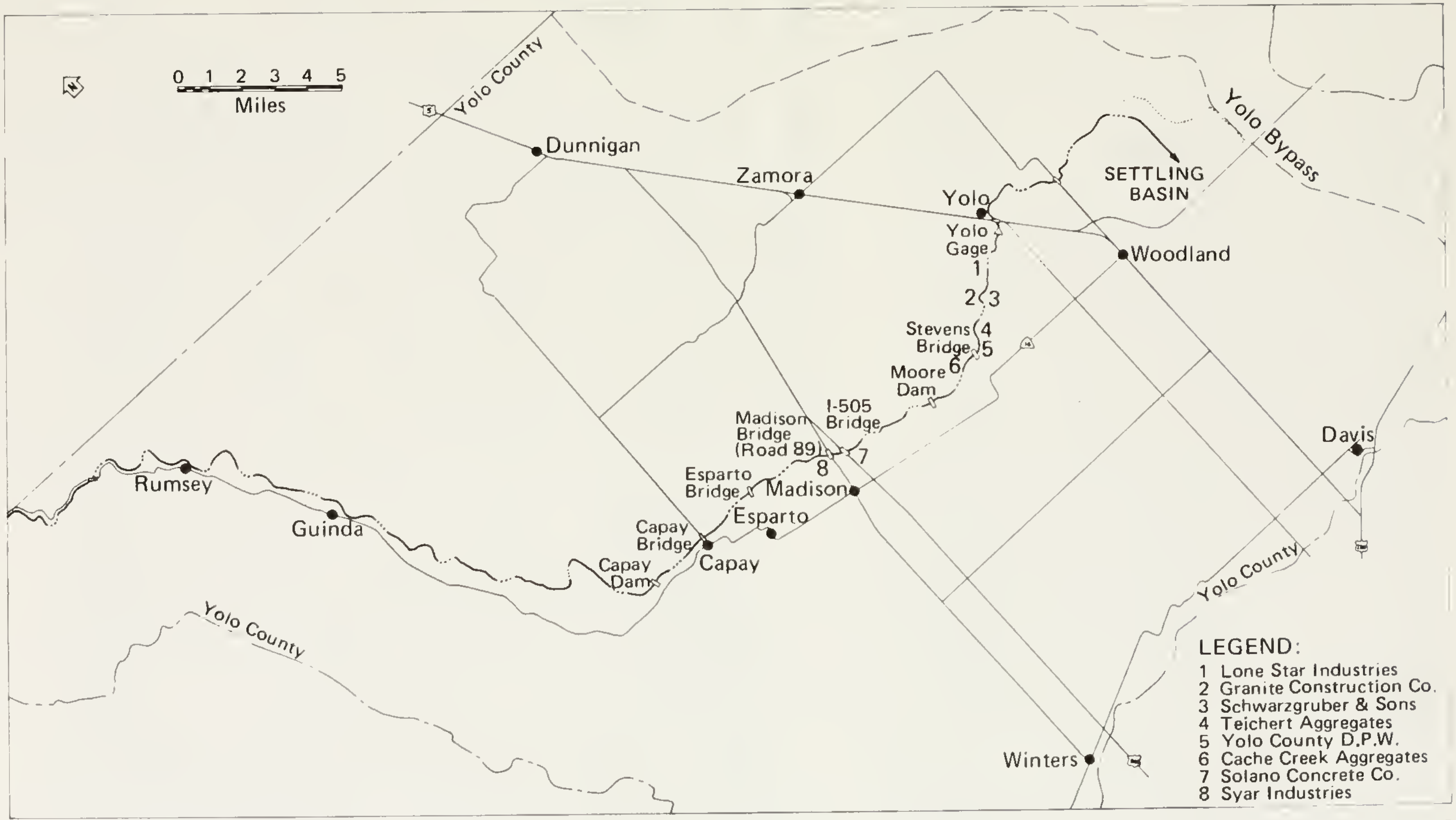

Figure 2. STUDY AREA—MAN-MADE FEATURES

Over the past two decades, residents of Yolo County who have had a long-term close association with Cache Creek have observed and drawn attention to pronounced physical changes (e.g., streambed lowering, stream widening). They have also expressed concern over pronounced changes in the natural riparian environment. A concurrent lowering of the groundwater table has also been observed throughout much of Yolo County. Although some residents have concluded that such changes are due to the increased aggregate extraction operations and have expressed such allegations publicly, there have not been any studies to establish cause-and-effect relationships. Hence, there has not been a sound basis for formulating public policy regarding the management of aggregate extraction operations. The study reported herein is intended to remedy this situation.

AGGREGATE RESOURCES ADVISORY COMMITTEE

Since most of the aggregate companies on Cache Creek have been in operation for many years, the County Planning Department's official posture has been that they have been "grandfathered in" and are therefore relatively exempt from routine administrative controls. In 1972, however, a new company, Solano Concrete, applied for a Use Permit to conduct aggregate extraction operations on the creek. The provisions of the California Environmental Quality Act required that an Environmental Impact Report be prepared, describing the proposed extraction operations and the anticipated environmental impacts. This, plus reservations expressed by local residents, led the County Planning Department to prescribe rather specific conditions under which the extraction operations could take place. An indirect result of this public airing of the controversy over the aggregate industry's benefits and alleged adverse impacts was the decision by the Yolo County Board of Supervisors to establish an ad hoc study group. The Aggregate Resources Advisory Committee was formed in 1975 and described itself as follows:

> "The purpose of this committee is to examine the impact of gravel extraction in Yolo County, to evaluate alternatives and to recommend a course of action to the Board of Supervisors."
>
> "Concern that the high quality aggregate resources of Yolo County may be being depleted led to the need to understand the impact of gravel extraction on: sediment transportation, bank erosion, scour, stream channelization and meandering, groundwater recharge, agriculture, land values, air and noise pollution, environmental and aesthetic considerations as well as obtaining an estimate of needs for Yolo County to the year 2025 for aggregate. There is also concern that alternatives for management be recommended."
>
> "The committee should investigate the impacts of a series of alternatives between the extreme conditions of either eliminating aggregate extraction from the creek bed (to another source in or out of county), developing controls on recovery that will impose a minimum degree of degradation of the environment, or continuing relatively unchecked the removal of soil, sand and gravel from the area."
>
> "Included would be the formulation of policies that will allow compatible operations and activities. The evaluation will include an assessment of the geology-hydrology, environmental considerations, economics of aggregate operations, and regulations and management alternatives."

The committee is made up of people representing a broad spectrum of interests in Yolo County:

Sandy Motley, Advisory Committee Chairman

Ken Haussler, resource conservationist (Yolo County Assn. of Resource Conservation Districts)

Bruce Johnston, aggregate industry representative (Teichert Aggregates)

Robert Matthews, geologist (U.C. Davis faculty)

Robert Moeller, resource conservationist (Western Yolo Soil Conservation District)

Oliver Orrick, Director (Yolo County Flood Control and Water Conservation District)

Peter Richerson, environmentalist (U.D. Davis faculty)

Jim Robinson, aggregate industry representative (Solano Concrete Co.)

Verne Scott, hydrologist (U.C. Davis faculty)

The following persons were designated as alternate committee members and contributed to the study in a variety of ways:

- *Ernest Hurd,* aggregate industry representative (Teichert Aggregates)
- *William McAnlis,* Manager (Yolo County Flood Control and Water Conservation District)
- *Joe Scalmanini,* hydrologist (U.C. Davis)
- *Frank Sieferman,* resource conservationist

WOODWARD-CLYDE CONSULTANTS' INVOLVEMENT

In October 1975 the Advisory Committee sought the assistance of outside consultants to provide an objective technical investigation of the conditions on Cache Creek and the validity of the allegations directed against the aggregate industry. The primary purpose of the study was to develop a sound basis for establishing a viable management policy which the Committee could recommend to the Board of Supervisors. Woodward-Clyde Consultants of San Francisco was awarded a contract to conduct the study in December 1975.

A provision of the contract was that the consultant would draw heavily upon the experience and expertise of the well-qualified Committee members and would meet with the Committee regularly to maintain a high degree of communication. This goal was accomplished by holding meetings every two to three weeks throughout the study period.

It should be noted that this report is intentionally brief in its coverage of topics which are quite complex indeed. Such an approach has been possible only because the close communication among the Committee members and the consultant have allowed the detailed considerations surrounding these findings to be discussed in considerable depth at the meetings. In general, this report states observations and conclusions, presents the basis for these conclusions, but does not present either raw data or the formalized analyses which led to the conclusions.

Supporting information has been transmitted to the Planning Department to be retained in public files. This approach was recommended in the interest of making the report useful to a wide spectrum of the general public.

Section II

SCOPE AND APPROACH

Section II

SCOPE AND APPROACH

The objectives of this study were to make an independent, technically sound analysis of:

- present conditions on Cache Creek
- aggregate extraction operations on Cache Creek
- cause-and-effect relationships regarding the major adverse conditions which have been observed (e.g., streambed lowering, stream widening, groundwater depletion)
- alternative means of controlling future problems (e.g., alternative management policies, alternative aggregate sources)
- the implications of adopting such alternatives (e.g., environmental, political, socioeconomic)

The purpose of conducting this study was to provide the Aggregate Resources Advisory Committee with an understanding of the situation, the problems, and the potential solutions, such that they could advise the county Board of Supervisors regarding the establishment of public policy to manage future aggregate operations.

It should be noted that at the outset of the study certain constraints were set forth to limit the scope to manageable proportions. First, the scope of the study was to include consideration of available information only (as opposed to the collection of new field information or physical measurements). Secondly, it was agreed that the study should focus on Cache Creek as it exists now and may be expected to exist without major changes by other projects (this was done to preclude the expenditure of limited time and funds in a duplicate analysis of

Corps of Engineers' plans). Thirdly, the geographic scope of the study was limited to focus on those areas where important impacts of aggregate operations have occured or could be expected to occur. This originally extended from the settling basin to the town of Rumsey, but later narrowed in focus to extend from the town of Yolo to the Capay Dam.

The study considered alternative aggregate sources and alternative ways to deal with some of the problems which were allegedly caused by extraction operations, but these have been limited in the depth of consideration (e.g., the study covers some of the more important issues regarding groundwater resources but is not a comprehensive treatise on that subject).

Section III

DESCRIPTION OF STUDY AREA

Section III

DESCRIPTION OF STUDY AREA

The following sub-sections describe those characteristics of the study area which are pertinent to understanding the discussion of aggregate extraction operations, their resultant impacts and alternative management plans. The subjects covered include the geotechnical setting, hydrology, the environmental setting, and the socioeconomic setting. It should be noted that the information provided herein is intended to be an overview which will provide the reader with general background information which should help to place the technical discussions of subsequent sections in proper perspective.

Appendix A is a Bibliography which has been provided to assist interested readers in finding more detailed reference materials on subjects covered here only in summary. Appendix B is a Glossary of technical terms.

GEOTECHNICAL SETTING

The following discussion presents general information on the geotechnical characteristics of the area: the regional and local geology and the soils. It is intended to introduce the subject and provide a background which will be developed in greater depth in subsequent sections. Figure 3 is a map of regional geology. The interested reader may wish to pursue the subject further through the reference works cited in the Bibliography, Appendix A.

Geology

The following description of the basin has been excerpted from a recently completed, comprehensive study of Yolo County water resources:

The Cache Creek Basin consists of channel deposits which extend up to half a mile north and 1-1/2 to 3 miles south of the creek and roughly parallel it between the Coast Range on the west and the Dunnigan Hills on the east. Gravel deposits extend to depths of 50 to 150 feet below the land surface. These are underlain by a generally fine grained section of hard clay beds and occasional layers of hard sand or cemented gravel. They are believed to be part of the Tehama formation which crops out in the Dunnigan Hills to the east and in the foothills to the west.

The land surface in the Hungry Hollow area consists of unconsolidated alluvial fan deposits. Tehama formation and related continental sediments underlie the alluvial fan deposits and are composed of clay, hard silt, and some sand and gravel.

Extending south between Cache and Putah Creeks and east between the Coast Range and the Plainfield Ridge, is an isolated alluvial plain, part of the Sacramento Valley but separated from the main valley trough by the Dunnigan — Plainfield anticline. Its lithology is essentially

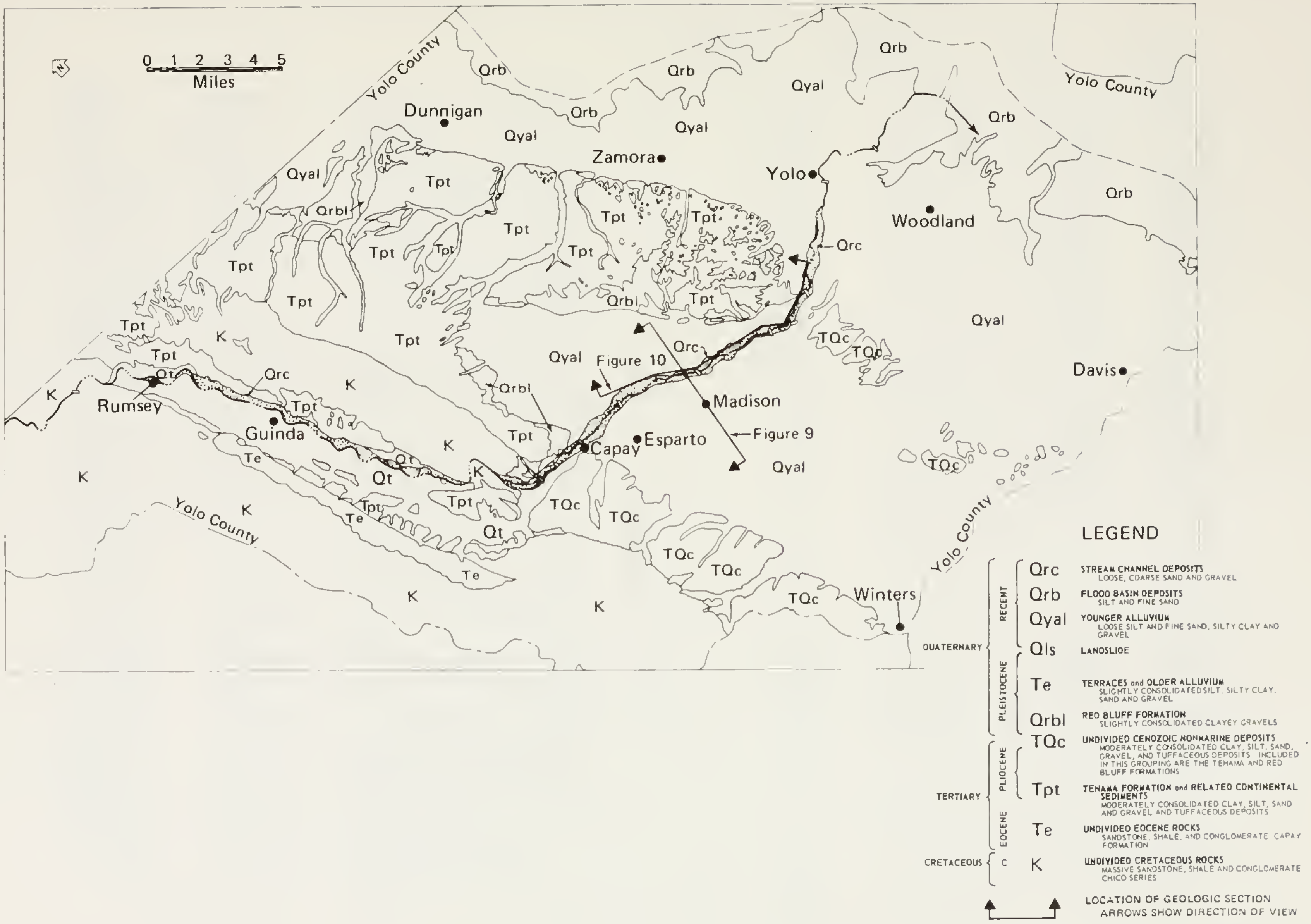
0 1 2 3 4 5
Miles
Yolo County
Dunnigan
Zamora
Yolo
Woodland
Davis
Madison
Esparto
Capay
Guinda
Rumsey
Winters
Figure 10
Figure 9
Qrb
Qyal
Qrc
Qrbl
Tpt
TQc
K
Qt
Te
LEGEND
QUATERNARY
RECENT
Qrc STREAM CHANNEL DEPOSITS LOOSE, COARSE SAND AND GRAVEL
Qrb FLOOD BASIN DEPOSITS SILT AND FINE SAND
Qyal YOUNGER ALLUVIUM LOOSE SILT AND FINE SAND, SILTY CLAY AND GRAVEL
Qls LANDSLIDE
PLEISTOCENE
Te TERRACES and OLDER ALLUVIUM SLIGHTLY CONSOLIDATED SILT, SILTY CLAY, SAND AND GRAVEL
Qrbl RED BLUFF FORMATION SLIGHTLY CONSOLIDATED CLAYEY GRAVELS
TQc UNDIVIDED CENOZOIC NONMARINE DEPOSITS MODERATELY CONSOLIDATED CLAY, SILT, SAND, GRAVEL, AND TUFFACEOUS DEPOSITS INCLUDED IN THIS GROUPING ARE THE TEHAMA AND RED BLUFF FORMATIONS
TERTIARY
PLIOCENE
Tpt TEHAMA FORMATION and RELATED CONTINENTAL SEDIMENTS MODERATELY CONSOLIDATED CLAY, SILT, SAND AND GRAVEL AND TUFFACEOUS DEPOSITS
EOCENE
Te UNDIVIDED EOCENE ROCKS SANDSTONE, SHALE, AND CONGLOMERATE CAPAY FORMATION
CRETACEOUS
C
K UNDIVIDED CRETACEOUS ROCKS MASSIVE SANDSTONE, SHALE AND CONGLOMERATE CHICO SERIES
LOCATION OF GEOLOGIC SECTION ARROWS SHOW DIRECTION OF VIEW

Figure 3. REGIONAL GEOLOGY

the same as the Hungry Hollow area with unconsolidated alluvial fan deposits at the surface underlain by clay, hard silt, and some sand and gravel.

The Plainfield Ridge (an extension of the Dunnigan Hills) is an isolated body of dissected alluvial deposits. The area contains hard silt and clay, sandstone, and cemented gravel of the Tehama formation.

Extending from the Plainfield Ridge to the Yolo Bypass is a broad low plain; alluvial fan deposits composed of unconsolidated clay and silt, sand, and gravel, ranging to 200 feet deep. (Scott, et al., 1975).

Additional detailed descriptions of geology are present, in context, in other parts of this report.

Soils

The soils of the area have been described as follows:

> "The fine alluvium deposits on about sixty three percent of the County's surface provide large areas of excellent soils. Almost one hundred thousand acres of the County's surface is of the finest quality in the world (Class I). Another one hundred forty five thousand acres are good land with minor limitations (Class II). Class III and IV soils are also considered as land suitable for cultivation by the U.S. Soil Conservation Service land capability classification system. Approximately two hundred eighteen thousand acres fall within this classification. A large percentage of this land is classified as prime soil based on the high annual gross value of the agricultural products produced on this land."
>
> "The Class I soils are of the Yolo-Brentwood Association consisting of well-drained silt loams and silty clay loams formed from sedimentary rock. These soils are deep and highly fertile. Soils of this association are principally used for irrigated orchards, row crops and field crops."
>
> "Class II soils are of the Rincon-Marvin-Tehama, Capay-Clear Lake and Sycamore-Tyndall Associations made up of nearly level loams, silty clay loams, silty clays and very fine sandy loams. Most of the soils in these associations have a high degree of

inherent fertility and are deep. The Rincon-Marvin-Tehama Association is good for irrigated orchards, row crops and field crops. The Capay-Clearlake Association is chiefly used for irrigated row crops and field crops, dry farmed field crops and pasture. The Sycamore-Tyndall Association is used for row crops, hay crops, orchards, irrigated pasture, and dry farmed grain." (*Conservation Element* of the Yolo County General Plan).

HYDROLOGY

The following discussion presents basic information on the hydrologic characteristics of the study area, including brief discussions of basin morphology, surface waters, the groundwater, basin water quality, and water use. Because some readers may wish to pursue some of these topics further, additional information has been provided in Appendix C. References listed in the Bibliography (Appendix A) may also be of interest.

Basin Morphology

Cache Creek drains an hourglass-shaped area about 50 miles long and 5 to 16 miles wide, to the Sacramento River drainage system. The principal tributaries are the North Fork and Bear Creek.

The upper portion of the basin, (which is about 25 miles long and 6 to 12 miles wide) lies to the north and east of Clear Lake and is characterized by northwest-trending ridges with rugged steep-sloped peaks up to 5000 feet in elevation separated by only a few narrow valleys. The mountainous areas are covered by dense growths of brush with some pine and oak trees.

About a third of the overall Cache Creek drainage area is tributary to Clear Lake, which traps virtually all sediment originating upstream. Water from Clear Lake is released into Cache Creek, where it flows for about 30 miles through a rather steep canyon before entering Capay Valley.

The area below Clear Lake exhibits considerable variety in factors which affect sediment availability and transport (e.g., stream gradient, geology, soils, topography, ground cover, land use). For example, Cache Creek's largest tributary, North Fork Cache Creek, originates in rugged hills with rocky outcrops and dense vegetation, whereas in the lower reaches of North Fork Cache Creek (and also in Cache Creek proper) the

channel extends through an alluvial valley with deposits of silt-clay, sand, and gravel. This valley is generally badlands-type topography, subject to intense erosion.

Further downstream, Cache Creek and Bear Creek flow through an area of easily erodible sedimentary formations that are relatively barren of vegetation. Thus, the normal increase of sediment discharge downstream due to increasing drainage area and water discharge is supplemented by these highly erodible areas.

The lower portion of the Cache Creek basin lies to the south of the town of Rumsey and is characterized by the alluvium-filled trough of Capay Valley, which is bordered on the west by the northwest-trending Vaca Mountains and on the east by the Rumsey Hills and the gently sloping alluvial plain of the Sacramento Valley. This lower basin is about 25 miles long and 5 to 16 miles wide.

The floor of Capay Valley has been extensively cultivated for agriculture. Badlands topography is characteristic of the foothills along the western edge of Capay Valley.

Between Capay Valley and the alluvial fan area, the creek flows for several miles through a narrow valley in the Capay Hills. These hills are typical of the Coast Range at lower elevations, where grasslands are broken by scattered bedrock outcrops and trees. The generally smooth appearance of these hills is broken here and there by step-like topography, where surficial slump and soil creep have gradually created gullies. Runoff concentrates in these gullies, speeding up erosion and transport of sediment to Cache Creek.

The Cache Creek channel widens considerably below the Capay Hills. Sediment deposition occurs over a wide area on the flat alluvial plain. The extensive deposits of sand and gravel along Cache Creek between the town of Capay and Yolo are a major source of aggregate.

The natural channel retains good definition near the town of Yolo. Levees have been constructed along both banks of the channel between Yolo and the settling basin to provide flood control for the Woodland area.

Surface Waters

The following description has been excerpted from a recently completed, comprehensive study of Yolo County water resources (Scott, et al, 1976):

> "The principal surface water supplies of Yolo County include the numerous creeks and streams which flow from the Coast Range and foothills into the valley portion of the County as well as the major streams: Cache Creek, Putah Creek, the Sacramento River, and the Colusa Basin Drainage Canal."
>
> "Precipitation in the County occurs mainly as a result of cyclonic storm fronts and most of the rainfall occurs during 6 to 12 hour periods. Precipitation influences surface water hydrology over relatively short periods. Little rainfall is retained in the mountainous areas due to the nature of the soils and slopes, and high percentages of runoff result. In most areas of the County, runoff reaches large streams, such as Cache Creek or Putah Creek, soon after reaching the alluvial plains and thus intermingles with waters flowing from outside the County."
>
> "Surface flows from outside the County have a significant impact on surface water hydrology throughout the year. Winter rainfall is stored in reservoirs outside the County and released through the summer months to streams flowing through or bordering the County: releases from Lake Berryessa to Putah Creek, and releases from Clear Lake and the newly constructed Indian Valley Reservoir to Cache Creek."
>
> "Clear Lake Dam, at the head of Cache Creek, was constructed in 1914 at the outlet of Clear Lake, a natural lake prior to construction of the dam. The operation of the dam which controls releases, is governed by the Gopcevic and Bemmerly Decrees. Active storage in the Lake is limited to approximately 314,000 acre-feet and produces and average annual yield of 140,000 acre-feet."

> "Indian Valley Dam and Reservoir was completed in 1975 on the North Fork of Cache Creek, 11 miles upstream from the confluence of the North Fork and Cache Creek. The gross capacity of the reservoir is 300,000 acre-feet of which 40,000 acre-feet are reserved for flood control. The design annual yield is 48,000 acre-feet."
>
> "Historically, diversions from Cache Creek for irrigation date back to 1856. The Capay Dam, located just above Capay on Cache Creek, diverts water into the Adams Canal to the north and Winters Canal to the south."

USGS streamflow records indicate that Cache Creek has an average discharge of 516 cubic feet per second (373,800 acre-ft per year), based on 70 years of record (measured at the Yolo gaging station). Its maximum discharge over that period was 41,400 cubic feet per second, measured in February 1958. The creek typically runs dry in most reaches during the summer and fall, has moderate flow from December to April, and peak flows during January and February.

Groundwater Basin

The following discussion covers the groundwater basin deposits, the location and movement of groundwater, and the location of other aggregate deposits (located off the present channel of Cache Creek).

Basin Deposits. The main groundwater basin in Yolo County underlies the valley floor west of Capay Dam (Figures 1 and 2). This groundwater basin is composed of two distinct geologic units, the alluvium and the underlying Tehama formation. The formations are similar in origin and composition but differ in permeability. The alluvium is relatively thin but is composed primarily of very permeable gravel with minor clay layers. The Tehama formation is very thick but is composed primarily of clay and silt with minor quantities of sand and gravel.

The alluvium was deposited upon the eroded surface of the Tehama formation in the Cache Creek alluvial fan and outwash plain during the last few hundred thousand years. The sediments in the alluvium were derived from the watershed of Cache Creek by erosion of the Tehama and

related gravelly deposits. The origin of the gravel deposits in the alluvium is discussed in detail in Section IV, "Cache Creek Aggregate Deposits."

The groundwater basin is divided into an eastern and western portion by the Dunnigan Hills and their southern extension called the Plainfield Ridge. The Dunnigan Hills and Plainfield Ridge are part of an upwarp structure (anticline) composed of the Tehama formation. The reason for the division into two is that the Dunnigan Hills and Plainfield Ridge act as a barrier to the subsurface movement of groundwater that normally occurs toward the east. This results in the water table standing at a somewhat higher elevation west of the Plainfield Ridge. The western portion of the groundwater basin extends from Hungry Hollow on the north to the county line on the south, and from the hills north and south of Capay Dam eastward to the Dunnigan Hills and Plainfield Ridge. The eastern portion of the groundwater basin extends eastward from the Dunnigan Hills and Plainfield Ridge to the Yolo Bypass and from the county line on the north to Putah Creek on the south. The western portion of the basin is referred to in this report as the upper groundwater basin and the eastern poriton is referred to as the lower groundwater basin (Figure 1).

The alluvium is by far the most important groundwater producing unit in the groundwater basin. The majority of groundwater pumped from wells is pumped from the alluvium, and yields often exceed 2,000 gallons per minute. In contrast, the Tehama yields only a few hundred gallons per minute to wells several hundred feet deep. Specific capacity values are usually less than 10 for the Tehama formation, while the alluvium has specific capacity values of 100 or more. Specific capacity is defined as the amount of water produced in gallons per minute per foot of drawdown in the pumping well. It is a measure of the transmisivity of the aquifers.

In the upper groundwater basin the alluvium reaches its greatest thickness between Esparto Bridge* and Madison Bridge and is approximately 150 feet thick. Between Madison Bridge and Moore Dam the alluvium is approximately 80 feet thick, and between Moore Dam and Stevens Bridge it is 60 feet thick. Downstream from Stevens Bridge in the lower basin the alluvium thickens considerably to perhaps 200 feet. The thinning of the alluvium is most pronounced in the Dunnigan narrows (located between outcrops of Tehama formation in the Dunnigan Hills and Plainfield Ridge) where the alluvium is underlain by the Tehama formation. The hills act as a control on the thickness of the alluvium along this section of the creek channel.

The alluvium between Esparto Bridge and Moore Dam is divided into two main gravel units separated by an extensive clay layer (shown in Figure 10). The upper gravel unit extends from near ground surface to a depth of approximately 60 feet or less and the lower unit extends from a depth of about 80 or 90 ft to the bottom of the alluvium at a depth of about 150 ft. The extensive clay layer that separates the two averages about 25 to 30 ft in thickness, except about 3 miles upstream from Moore Dam where the clay layer is consistently about 10 to 15 ft thick.

The gravel aquifers in the alluvium are overlain by an extensive silt and clay layer that is 6 to 10 ft thick near the creek channel and 20 to 50 ft thick within a few miles of Cache Creek. This surface layer supports the abundant agricultural production in the county. Cache Creek has cut down through the clay layer so that the underlying gravel deposits are exposed in the channel. The aggregate industry is currently mining these exposed gravel deposits which extend beneath the capping clay layer for several miles on either side of the creek.

---

*Esparto Bridge is the bridge where Road 87 crosses Cache Creek. Madison Bridge is on Road 89, Stevens Bridge on Road 94B, and Capay Bridge on Road 85.

Groundwater Movement. Groundwater moves generally from west to east in the Cache Creek groundwater basin. The general direction of movement is shown by the groundwater contours in Figure 4. Groundwater moves at right angles to the contours and down the gradient defined by them. The configuration of the groundwater contours has remained essentially unchanged since the first contour map produced in 1912-13. Therefore, the direction of movement of groundwater is generally similar from year to year. Groundwater moves south toward Cache Creek from the Hungry Hollow area and is responsible for the high water table near Cache Creek. South of the creek, groundwater moves westerly toward the Plainfield Ridge and southerly toward Putah Creek.

The low permeability of the Tehama formation causes the Plainfield Ridge to act as a barrier to the eastward movement of groundwater in the alluvium. Groundwater moves slowly westward through the Plainfield Ridge and more rapidly through gaps in the ridge (these gaps were eroded centuries ago as old channels of Cache Creek that were backfilled with permeable alluvium). In general, the permeable alluvium in the Dunnigan narrows averages about 50 ft in thickness but reaches a depth of about 80 ft in some old channels. The alluvium that fills these channels is usually composed of a coarse, very permeable gravel. The restriction in the eastern flow of groundwater caused by the Plainfield Ridge has resulted in the historically high groundwater table in the upper basin.

Location of Off-Channel Gravel Deposits. Water well logs analyzed during this study clearly show that extensive gravel deposits are present beneath a thin capping layer of silt and clay for several miles on either side of Cache Creek. The quality of this gravel is probably the same as the gravel now present in the stream channel, because these gravel deposits are the shallowest (and therefore the most recent) portions of the Cache Creek alluvial fan. The rock types in the gravel are undoubtedly also the same as the present stream channel deposits (at least at shallow depth) because the source area is the same.

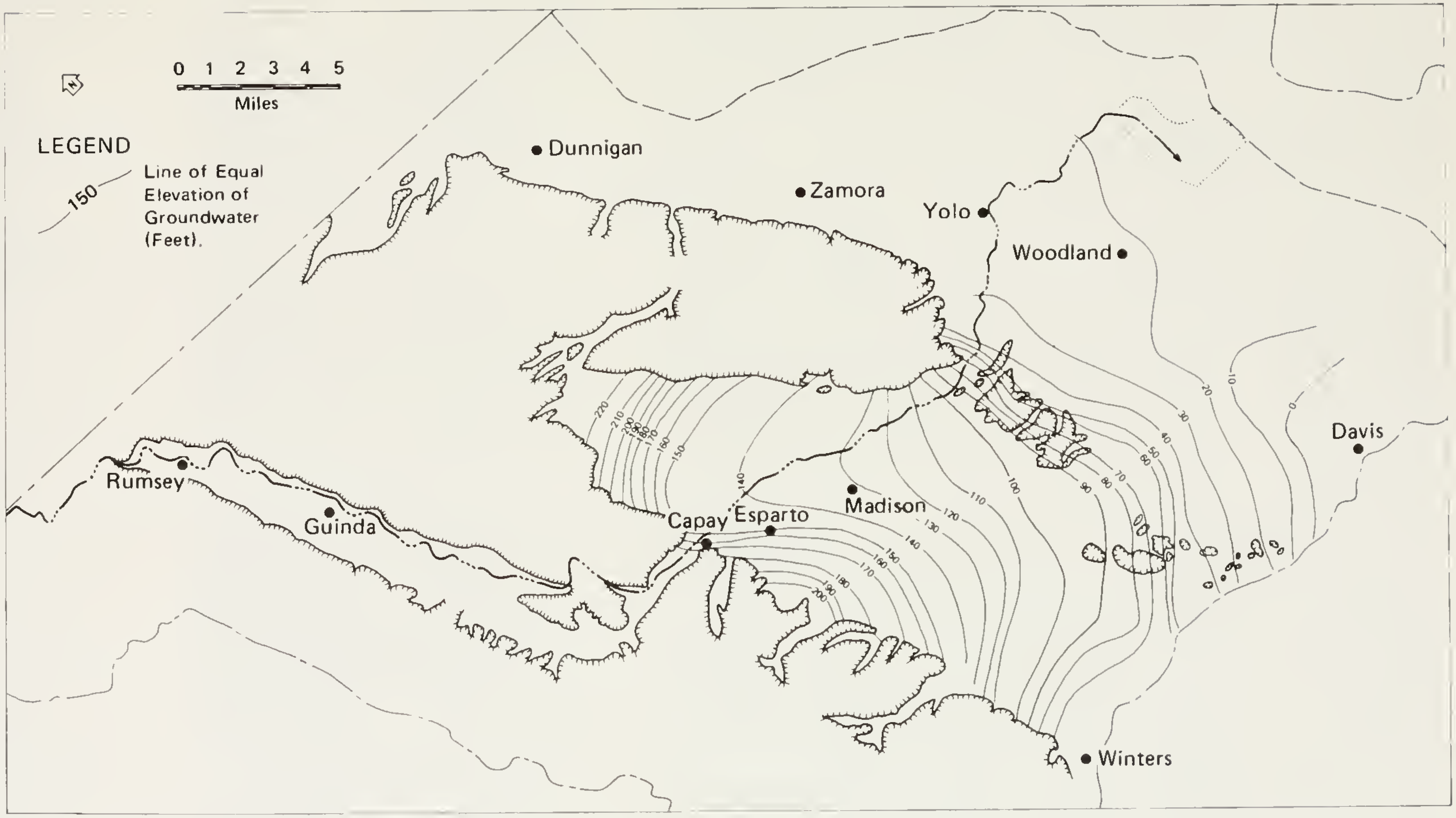

Figure 4. GROUNDWATER CONTOURS FALL 1959.*

*FROM: DEPARTMENT OF WATER RESOURCES (1961)

Between 8 and 18 ft of bed lowering in Cache Creek has occurred since about 1950. The likelihood is that the gravel deposits of the present stream channel have been derived from both the off-channel gravel deposits (through channel widening) and from gravel exposed by downcutting during the last few years. In other words, the gravel now exposed in the stream channel is an old deposit rather than bedload that has been brought down from upstream during historic flood periods.

In short, abundant gravel deposits exist for several miles both north and south of the present channel of Cache Creek beneath a layer of silt and clay ranging in thickness from approximately 10 to 15 ft near the creek channel to between 30 to 60 ft farther away. Between Moore Dam and Stevens Bridge, the gravel deposits occupy a narrow strip in the Dunnigan narrows between outcrops of the Tehama formation. Downstream, from Stevens Bridge to the constriction in the channel (1.5 miles upstream from Yolo), gravel deposits again occupy a wide area extending a mile or more both north and south of the present channel. In this latter area, the overlying silt and clay layer is thicker and averages 20 to 30 ft in thickness.

Water Quality

The water quality of lower Cache Creek is considered satisfactory for use as agricultural irrigation water. Use of the water is restricted, however, to those crops which are not sensitive to boron. Bear Creek, a tributary to Cache Creek, has a high boron content and contributes this element to lower Cache Creek waters. Since the candidate management options for the aggregate industry do not differ appreciably in their effects on water quality, this subject has not been pursued in greater depth.

Water Use

The following description has been excerpted from a recently completed, comprehensive study of Yolo County water resources (Scott, et al., 1975):

"Applied water requirements for irrigated agriculture are affected by crop acreages, consumptive use by specific crops, irrigation efficiencies, water reuse, and contributions by rainfall. Irrigated acreage in 1970 totaled 233,200 acres with a total agricultural water requirement of 804,900 acre-feet."

"Based on the perennial yield of the groundwater basins and pumpage from the basins, the County is in a groundwater overdraft situation. Over the study period, Countywide average annual overdraft was 12,000 acre-feet. If supplemental imported water is not available by 1990, the annual overdraft in the County will increase to about 90,000 acre-feet under average conditions. However, if supplemental imported water is available, increases in applied surface water could be made to meet increasing total water requirements. Under such a condition, groundwater pumpage could match the perennial yield, 327,000 acre-feet per year in 1990, resulting in stabilization of groundwater levels and elimination of overdraft.

"Assuming supplemental water is available by 1990, irrigated agriculture is expected to expand to 270,000 acres with a total agricultural water requirement of 945,600 acre-feet. If supplemental water is not available, limited groundwater supplies, particularly in the western Colusa, Cache Creek, and Lower Cache-Putah basins, are expected to limit development of irrigated agriculture to 253,000 acres with a total agricultural water requirement of 884,100 acre-feet."

"By 2020, imported supplemental surface water is expected to be available in the County. Of the total acreage currently classified as irrigable in the County, 85 percent is expected to be developed by 1990 if supplemental surface water is available and all irrigable acres are expected to be developed by 2020. Accordingly, by 2020, irrigated agriculture is expected to expand to 320,000 acres with a total agricultural water requirement of 1,113,000 acre-feet per year."

"Total municipal and industrial water requirements in 1970 were 29,000 acre-feet or about 3.5 percent of Countywide total water requirements. Municipal and industrial requirements are expected to increase, independent of supplemental surface water availability, to 53,400 acre-feet in 1990."

ENVIRONMENTAL SETTING

The following is a description of the present habitats in the Cache Creek area. It is presented in order to provide a background for considering the environmental aspects of the area in perspective with other aspects (e.g., physical, social, economic). The interested reader may wish to consult the numerous reference works cited in the Bibliography, Appendix A.

Present Habitats

Conditions within the area of Cache Creek that are most affected by the aggregate extraction operations (directly or indirectly) can be described in terms of five main biological communities:

- aquatic
- streambed
- stream bank slope
- top of stream bank
- adjacent plains

All of those have been altered by a variety of human activities (e.g., aggregate extraction, farming, construction of housing, roads, highways, irrigation facilities).

Aquatic. The aquatic community of Cache Creek is relatively unproductive in terms of sports fish or aquatic vegetation, primarily because the summertime flows in Cache Creek are very low, and much of the creek goes dry. The fish in Cache Creek are primarily warm water species such as carp, catfish, and some bass. There apparently are no significant salmonid populations in Cache Creek at present, although according to a recent report by the Corps of Engineers, there have been salmonids (steelhead and salmon) and other anadromous fish in Cache Creek in the

past. Large pond areas do form in lower Cache Creek as the flows recede, and these are typically occupied by fish (particularly carp), algae, and some other plants. However, as summer progresses, these ponds dry up, and their contents are left stranded to die.

The streambed itself has been significantly altered in the lower reaches of the stream, due to aggregate extraction and the associated bed and bank erosion. There are few algae or other aquatic plants in the stream. The few plants that are able to grow in the streambed are isolated and probably subject to displacement during bed disturbance and/or aggregate extraction operations.

The aquatic community below Capay is comprised of unstable populations of relatively few ephemeral or opportunistic species. The recruitment of new individuals to these populations probably comes from upstream areas during higher flow periods. These populations become stranded during low flow periods and are eventually lost as the ponds dry up. This type of ephemeral biological community has relatively little intrinsic or ecological value to the stream ecosystem.

Upstream from the aggregate extraction operations (towards Capay Dam) there is an increase in the stability of aquatic habitats (i.e., surface water pools), and stream conditions remain extant through most or all of the year. Upstream from Capay Dam there are permanent pools of water in which there are carp and other warm water fish as well as aquatic vegetation, including algae, tules, and other species of attached aquatic plants.

Streambed. The streambed in the area of the aggregate extraction operations has been significantly altered for many years, and there is virtually no significant vegetation within the basins where the scrapers regularly operate. Vegetation beyond sparse clumps of willow and tamarisk will not become established in these areas as long as extraction

operations continue. This is because there is little suitable soil to provide the plants with the support or the nutrients needed for growth and because even when small clumps of plants do become established they are likely to become dug up or otherwise impacted by the activity of the machinery. Upstream from the extraction areas (towards Capay Dam) there is an increase in the amount and diversity of the streambed and riparian vegetation. This vegetation appears to be comprised mainly of carex, tules, willows, tamarisk, grasses, and shrubby plants. This species composition and the small size of the plants in this community suggests that the community is temporally unstable, probably due to a combination of the periodic washing-out by floods and the downstream movement of sediments.

The streambed vegetation provides shelter, escape cover, food, and some nesting areas for several species of birds. Probably relatively few small mammals utilize the small thickets and clumps of vegetation in the streambed itself.

Stream Bank Slope. The slope area (the transition zone between the streambed and the tops of the banks) in the regions of the extraction operations is routinely and substantially affected by erosion, undercutting, dumping of debris, and other disturbances. However, some riparian vegetation and small trees do grow on these banks, especially upstream from the extraction operations. The vegetation is comprised of willows, tamarisk, blackberries, thistles, grass, cottonwoods, poplar, and several other species of shrubs and forbs. On the higher portions of the slope there are also a few oaks, alders, sycamores, and occasional walnut trees. This habitat provides shelter, food, escape cover, and nesting sites for a large number of birds and for some small mammals (e.g., rodents, rabbits, feral cats, rats, and possibly raccoons).

Top of Stream Bank. There are a variety of habitat types on the upper bank region between the edge of the creek bank and the farm land. In a relatively few places below Capay Dam, there are several somewaht "natural" vegetative communities comprised of oak, sycamore, poplar, black walnut, and willows. However, there are also several species of introduced trees including tamarisk, pecan, and others. Much of what is present is either introduced or could be considered a successional stage in a natural community.

Most of the upper bank vegetation along Cache Creek (up to about Capay Dam) shows signs of man-induced disturbances. In several areas the farming activities (and/or clearing for roads, houses) extend down to very near the creek banks, and there is no native vegetation left. In other areas (e.g., Farnham's small nature preserve) there are relatively undisturbed areas of trees and other understory vegetation (which, although not "native" is good wildlife habitat, nonetheless). These areas, along with the upper bank habitats where trees and understory vegetation is present, are probably the most diverse, productive, and ecologically important of the habitats associated with the creek.

Adjacent Plains. Beyond the upper bank there is little native vegetation left, and the vegetative communities of the plain are comprised mostly of row, field, or orchard crops. In many places farming has extended right up to the creek banks, while in others there is some buffer zone between the creek bank and the farm land (often comprised of only an access road, but in some cases the upper bank community described above). The crops of the plain are largely monocultures and do not support a diverse wildlife community. The principal components are probably birds, insects, and some rodents.

Importance of Present Habitats

The habitats present within and along Cache Creek are important because they provide a source of wildlife, provide some degree of erosion

control, and contribute to recreation and aesthetic enjoyment (although the latter are limited because the "natural" areas are so small now). Most of the wildlife that is present in Capay Valley utilizes the habitats of Cache Creek to a greater or lesser extent. The riparian community and woodlands associated with the creek provide nesting areas for birds, food for birds and small animals, escape cover and shelter from the elements for all species. The importance of the habitats associated with the creek increases downstream from Capay Dam, where distances to the more or less "natural" woodlands and other vegetative communities of the surrounding hills are longer. The major wildlife component of these communities are the birds, but there are relatively large populations of feral cats, rabbits, and rodents. There may be raccoons, deer, skunk, opposums, and grey fox, as well. Bird species such as quail, dove, and numerous passerine birds are abundant in the vegetation of the creek banks and streambed, particularly in the winter time. In the lower reaches of Cache Creek renewal of the bird and animal populations is probably largely due to recruitment from upstream populations and is not the result of successful breeding and recruitment from the immediate area. That is, these populations are ephemeral, unstable, and probably not ecologically significant. They are comprised mainly of opportunistic species taking advantage of islands of habitat that are suitable to them.

Upstream (in the region of Capay Dam and further upstream) the populations are probably significantly larger and are able to reproduce themselves at or near the site. In addition there is probably recruitment from even larger populations of plants and animals in the surrounding hills on either side of Capay Valley itself. The distance from the creek to these hills is relatively short and is much more easily traversed by these mobile species than are the rather long distances between the hills and lower reaches of Cache Creek. In addition the farming tends to be at a smaller scale, and there is less disturbance of the plains than there is in the lower reaches.

If disturbance to the plant communities were to somehow cease, they could be expected to establish rather dense communities within a few years and would be well on the way to reaching relatively stable climax conditions within one or two decades. The creek habitat and associated riparian community would return to some equilibrium (if not their "natural" state), and there would be a considerable increase in animal and bird populations and overall productivity (at least at the local level). So long as major farming activities occur and restrict the riparian community to a narrow band within the streambed and the immediately adjacent stream banks, the community will probably not be one of major ecological importance.

The present plant community is a relatively ephemeral, successional stage in the forest community of the Cache Creek region. Given time the present community would be replaced by a willow/cottonwood community. In the absence of other disturbances and over a longer period of time (say several decades) this in turn would become an oak dominated woodland community. Along with this succession of plant communities there would be an increase in diversity of wildlife and birds and probably an increase in the population sizes of some of the larger mammals including deer, grey fox, bobcats, raccoons.

The importance of vegetation to erosion control along Cache Creek is not well documented, but it seems reasonable to assume that the presence of trees, shrubs, and other vegetation along the stream banks would reduce erosion in several ways. First, it would tend to stabilize the soils and reduce the amount of undercutting and amount of downstream sediment transport. Second, during high flow and flood periods, the vegetation would tend to reduce the velocity and energy of the water movement, thereby reducing its ability to erode bank and bed deposits and move them downstream. In addition the vegetation itself would take up some portion of the water (through transpiration) which at moderate flows and low flows simply reduces the volume of water which will move downstream.

The plant communities have potential recreational value, but at present they are apparently not widely valued as a significant recreational resource in the Cache Creek area. Private ownership restricts access to much of the area. In general there is a lack of sports fish in the creek. Nor are there many recreational facilities (parks, picnic facilities) along Cache Creek. However, the local Audubon Society and individuals and groups interested in wildlife do utilize Cache Creek as a place for observing the activities of various wildlife species.

Other Environmental Considerations

The aggregate extraction operations do generate noise and dust which could constitute a considerable nuisance in the nearby vicinity, were there anyone living in close enough proximity. However, because the nearest residences are typically on the order of a mile or so from the noisiest parts of the operations, relatively few people are affected and then for relatively short periods of time.* The issues of noise generation and control are being discussed outside the context of this project and will not be dealt with any further, here. Dust is seldom a problem, beyond the boundaries of the operating areas.

Water pollution is not considered to be a problem at this time, since the operations are not conducted within the flowing portion of the stream and because all wash water is directed to off-stream disposal areas; large ponds which allow water to slowly percolate (and evaporate) away, without putting the fine silts back into the creek.

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*Note that the actual sound levels are not particularly high at the locations where the nuisance conditions are experienced, but they are notably higher than other sources and they are notably out of character with the types of sounds one usually associates with such a rural setting. Hence they have a nuisance impact which is out of proportion with their actual intensity.

Nor is air pollution from the extraction industry seen as being important enough to influence the selection of a management policy. There are considerable quantities of pollutants emitted from the diesel engines which power the numerous scrapers, trucks, and other types of equipment and from the asphalt hot plant. They are already under various types of control, however, and the ambient air quality is not so poor as to warrant placing more restrictive controls on the industry.

SOCIOECONOMIC SETTING

The following is a description of socioeconomic conditions and trends in Yolo County. It is intended to provide a background to allow socioeconomic factors to be balanced against environmental and various physical factors when one considers conditions in the area and assesses alternative aggregate management plans. The major topics discussed here include: demography, economy, employment and income, and public finance. The interested reader may wish to pursue these topics further through the references cited in the Bibliography, Appendix A.

Demography

The total Yolo County population grew from 65,700 in 1960 to a 1975 level of 100,700, a 53.2 percent rise (Table 1). Significant growth occurred in the cities of Davis and Woodland during the same period, but continued growth of this magnitude is not anticipated. As of April 1975, the population of Davis was estimated to be 31,800 people with Woodland having 25,400. These two cities account for over 56 percent of the total county population.

Table 1. POPULATION TRENDS

	April 1960	March 1969	April 1975
City of Davis	8,910	21,750	31,831
City of Woodland	13,524	20,600	25,389
City of Winters	1,700	2,271	2,520
East Yolo Area	25,032	25,207	23,880
Total Unincorporated	41,593	41,668	40,832
Total County	65,727	86,289	100,686

Source: Yolo County Planning Department 1975. *Special 1975 Census, Population Characteristics.*

Economy

The most recent federal economic census information indicates that Yolo County had 117 manufacturing establishments employing 4,300 people (as of 1972). The total manufacturing payroll was $34 million with production wages reaching $24 million. During 1972, *value added by manufacture* totaled $99 million.

The 1972 Census of Wholesale Trade enumerated 150 wholesale establishments with sales approaching $247 million. Paid employees totaled 1,470 and received a payroll of $15 million. The 740 retail trade establishments had sales of about $175 million. The industry employed 4,300 people and reported a total payroll of almost $22 million.

The 1972 Census of Selected Service Industries reported 700 establishments with receipts of $28 million. The total payroll for the 1,400 paid employees was about $7 million.

Yolo County's agricultural output in 1975 had a total value of almost $203 million. This was a 5.3 percent decrease from the previous year. Almost 91 percent of Yolo County's 662,000 acres are devoted to farms. Cropland acres total 397,000 with 253,000 irrigated acres and 146,000 acres of rangeland (woodlands and forests). Table 2 lists those crops which were individually valued at more than one million dollars in 1975.

Employment and Income

The 1975 Special Census conducted in Yolo County indicates that of those principal wage earners in the labor force the highest percentage were *professional, technical and kindred workers* (Table 3). *Managers, officials and proprietors* constituted ten percent of the occupations while nine percent of the residents were employed as *craftsmen, foremen and kindred workers*.

Table 2. YOLO COUNTY'S MAJOR CROPS (1975)

Crop	Value	Acreage
Tomatoes	$75,294,000	55,500
Sugar Beets	18,060,000	25,500
Rice	17,649,000	35,800
All Alfalfa	14,878,500	41,800
Wheat	13,057,000	62,000
Corn	9,919,000	25,000
Cattle & Calves	7,315,000	-
Grain Sorghum	6,888,000	32,000
Safflower	6,859,000	29,000
Almonds	5,598,000	11,660
Melons	3,500,000	-
Walnuts	2,504,000	5,300
Barley	2,415,000	25,000
Prunes	1,802,000	1,950
Pasture, Irrigated	1,350,000	18,000
Pasture, Other	1,187,000	250,000
Apricots	1,186,000	1,850

Source: Yolo County Department of Agriculture, _1975 Yolo County Agricultural Crop Report_.

Table 3. TYPES OF JOBS (1975 Special Census)

27%	Professional, technical, and kindred workers
13%	Managers, officials, proprietors, including farmers (owners and tenants) and farm managers
17%	Clerical and kindred workers
5%	Sales workers
11%	Craftsmen, foremen, and kindred workers
19%	Operatives and kindred workers
11%	Service workers, including private households
8%	Laborers, including farm laborers

The geographic locations of place of employment are primarily distributed between Woodland, Davis and Sacramento, as shown in Table 4.

Table 4. LOCATION OF JOBS (1975 Special Census)

27%	Davis area
21%	Sacramento area
29%	Woodland area
9%	East Yolo area
1%	Fairfield-Vacaville area
2%	Winters area
1%	Dixon area
1%	San Francisco — Oakland Bay Area
8%	Other

The 1970 Census of Population reports that median family income in Yolo County (1969) totaled $9,482 which was $1,247 less than the state average. Families with incomes below the poverty level constituted 10.6

percent of the total. The average annual per capita income for Yolo County residents was $2,990, about 16% below the statewide average of $3,614.

In 1973, Yolo County reported total personal income of $503,425,000 approximately 4.4 percent of the state total. Main contributors to the personal income total were wages and salaries, proprietor's income, and property income. Per capita personal income for Yolo County is given in Table 5 for the years 1971-1973. Again, Yolo County per capita personal income has been below the statewide average.

Table 5. PER CAPITA PERSONAL INCOME

	1971	1972	1973
Yolo County	$ 3,982	$ 4,294	$ 4,965
Average of all California Counties	4,634	4,976	5,487

Source: County Supervisors Association of California, California County Fact Book, 1975.

The 1975 Special Census reported that income was distributed among Yolo County families as shown in Table 6.

Table 6. PERCENTAGE OF FAMILIES WITHIN GIVEN GROSS ANNUAL INCOME BRACKETS

5%	Less than $2,000
13%	$ 2,000 - $ 3,999
11%	$ 4,000 - $ 5,999
10%	$ 6,000 - $ 7,999
10%	$ 8,000 - $ 9,999
20%	$10,000 - $14,999
14%	$15,000 - $19,999
11%	$15,000 - $29,999
6%	$30,000 or more

Public Finance

The major source of County governmental revenues is the property tax. This tax is levied upon land, improvements and tangible personal property with certain exemptions (e.g., federal, state, and most local government property, nonprofit educational, religious, charitable and cemetery properties). The tax measure is 25 percent of fair market value (appraised value) except for land restricted to certain "open-space" uses, nonprofit golf courses, owner-occupied single-family dwellings in R-1 or agricultural use zones assessable on restricted-use value.

Property values tend to vary considerably along the creek, ranging from about $1,500 to $1,800 per acre for good, productive agricultural land to only $100 to $200 per acre for unimproved "riverwash" land. Property tax rates also tend to vary considerably, depending upon location (i.e., the number and types of special districts the parcel is located in). The rates vary from the basic rate of $2.58 per hundred dollars of assessed value to several times that amount, such that the average property tax rate for the county as a whole is on the order of $11 to $12 per hundred dollars of assessed value. Expressed on another basis, the average property taxes for the county as a whole amount to about $47 per acre per year.

Historical/Archaeological Resources

The following has been excerpted from a recent environmental working paper prepared by the Corps of Engineers. The description of historical/archaeological resources is presented here to provide a background for considering the implications of allowing substantial future flooding or land erosion.

> "Clear Lake has been established as the site of human life at least 8,000 years ago. Before the coming of the white man, it is estimated that Lake County was inhabited by about 5,000 Indians, making it the most densely populated in the State. As a general

> classification, the Indians were of the Pomo family, related members of the Hoken family. The Lake Miwok held the drainage area of several small streams flowing into the very lowest mile or two of Clear Lake, and the southern bank of Cache Creek and the lake outlet for a short distance beyond. The Indians along Cache Creek and in the remainder of the lower basin were known as Patwin, a segment of the Wintun family, which occupied most of the Sacramento Valley. There are eight known Wintun village sites on Cache Creek."
>
> "Yolo was one of the original 27 counties created in 1850. Cache Creek is rich in historical lore and played a crucial role in the settlement and development of the region. One of the earliest uses by the white man was for fur trapping. French Camp, one mile east of Yolo on the north side of Cache Creek, was the campsite of Hudson Bay trappers. The first fur brigade in the Sacramento Valley, arriving in 1829, camped here. The earliest permanent settlements were also established along Cache Creek."
>
> "Properties within the Clear Lake-Cache Creek Basin which are listed in the National Register of Historical Places include the Rumsey Town Hall in Rumsey, the Canyon School north of Brooks, the Woodland Opera House in Woodland, and the Nelson Ranch in the vicinity of Woodland. The Gable Mansion in Woodland is a State historical landmark."

There is a known Indian mound near the farmhouse just southwest of the Stevens Bridge, but it does not appear to be in jeopardy.

During the course of this study, no sites of particular historical or archaeological value were identified as being in imminent danger of being flooded or eroded. It is recommended, however, that the Planning Department maintain contact with authorities on the subject when specific management plans are being formulated.

The interested reader may wish to pursue the subject of historical and archaeological resources by referring to the documents cited in the bibliography of the Conservation Element of the General Plan.

Section IV

DESCRIPTION OF AGGREGATE RESOURCES AND THE EXTRACTION INDUSTRY

Section IV

DESCRIPTION OF AGGREGATE RESOURCES AND THE EXTRACTION INDUSTRY

The purpose of this section is to acquaint the reader with the aggregate industry by describing commercial aggregates (their physical/chemical characteristics, their origin, their uses), the extraction industry in Yolo County (its production volumes, market, and role in the county's economy), and alternatives which could be considered. Additional information on this subject can be obtained through the references cited in the Bibliography, Appendix A.

COMMERCIAL AGGREGATE MATERIALS

Terminology

In commercial usage the term "sand" applies to rock or mineral fragments ranging in size from .003 to .25 inches. "Gravel" consists of rock fragments larger than .25 inch and ranging up to a maximum size of 3.5 inches.

Uses for Aggregate Material

Aggregate is commonly designated as the inert fragmental material which is bound into a conglomerate mass by a cementing material such as Portland cement, asphalt, or gypsum plaster. Portland cement concrete consists of sand and gravel surrounded and held together by hardened Portland cement paste (it commonly contains 15 to 20 percent water, 7 to 14 percent cement, and 66 to 78 percent aggregate). Asphaltic mixtures

used for paving, typically consist of sand, gravel, and mineral filler (i.e., material finer than .003 inch), uniformly coated with asphalt produced by refining petroleum. Except for the addition of mineral filler, sand and gravel used as asphaltic concrete must meet the same general physical requirements as the material used for Portland cement concrete.

Requisite Properties

A suitable aggregate has many requirements that are difficult to meet if only unprocessed material from natural deposits were used. Suitable material is composed of clean, uncoated, properly shaped particles which are sound and durable. "Soundness" and "durability" are terms used to denote the ability of aggregate to retain a uniform physical and chemical state over a long period of time. Individual particles must be tough and firm, possessing the strength to resist stresses and chemical and physical changes (e.g., swelling, cracking, softening, leaching).

The quality of aggregate, therefore, depends upon its physical and chemical properties and can be established by petrographic evaluation and laboratory testing (see Appendix D).

CACHE CREEK AGGREGATE DEPOSITS

Location, Origin, and Characteristics

The most important deposits of sand and gravel are concentrated in five major areas:

- in Indian Valley
- along the North Fork (between Chalk Mountain and the confluence with the main stream of Cache Creek)
- along the main stream (below the confluence, as far as Wilson Valley)
- along the main stream near Rumsey and Brooks
- along the main stream from Capay to Yolo

The North Fork of Cache Creek drops from elevations of approximately 5,000 ft and flows southeast in a steep, narrow gorge, transporting a relatively small amount of coarse gravel. Between Hough Springs and Indian Valley there are several small, shallow gravel bars. Stanton Creek, the main tributary to the North Fork, also transports relatively small amounts of gravel into Indian Valley. However in Indian Valley along these two streams, there are large deposits of sand and gravel. Unlike the gravel in the bars downstream, this gravel is derived exclusively from Franciscan formation rocks and is subangular to subrounded in the first cycle of transport. Note that the presence of the recently completed Indian Valley Dam prevents the transport of all but the finest silt-like materials past the dam.

Leaving Indian Valley, the North Fork of Cache Creek flows west through a steep-walled canyon and then abruptly turns south at Chalk Mountain, where it begins to cross the weakly-cemented conglomerates of the Cache formation. Sand and gravel is distributed along the stream from Chalk Mountain to its junction with the main branch and along the main branch for several miles below the confluence. The bulk of the sand and gravel is derived from the reworking of the Cache formation which crops out in the banks of the stream. The conglomerates of the Cache formation are composed of gravel similar in lithography to the gravel in Indian Valley.

Cache Creek streambed is alluviated from the junction with the North Fork to Wilson Valley. Below Wilson Valley Cache Creek flows through a deep canyon along which there are only a few unimportant, small bars.

Cache Creek flows through Capay Valley with the stream at grade, transporting sand and gravel in the bed load. Large gravel bars have formed near Rumsey and Brooks where the stream profile changes to a gentler slope. Part of the gravel derived from unmetamorphosed Mesozoic sediments above Rumsey consists of tabular sandstone fragments up to 8 inches in length that gradually diminish in size to a 3 inch maximum

downstream at Brooks. Much of the sand and gravel is derived from the weakly-consolidated, conglomeratic Tehama formation which comprises the valley floor, and the Pleistocene terraces which border the river plain. The character of the deposits changes as the bedload moves downstream, as increasing amounts of material are added from the Tehama formation and other older alluvial deposits, and the relative proportion of unmetamorphosed sandstones is decreased. At the southern end of Capay Valley, Cache Creek cuts across the trend of the stratified rocks through a narrow gorge, and sand and gravel are thus transported into the Sacramento Valley. From a point three miles above Capay, a new increment of gravel is derived from the Tehama formation, and sand and gravel are deposited alluvium on a broad alluvial plain from Capay to Yolo. There is a progressive decrease in gravel size from the 6 inch maximum at Esparto to the 1-1/2 inch maximum at Yolo.

Role as a Commercial Resource

Sand and gravel deposits occur in the present channel of Cache Creek and elsewhere in the alluvium beneath floodplain deposits. Deposits in the present channel are currently being extracted, because they are generally accessible and easily mined. Channel deposits are desirable as aggregate for many reasons. The natural abrasive action of stream transport has ground up and removed most of the soft, weak rocks, leaving only the harder and firmer materials. These in turn have undergone some degree of rounding and are mostly "sub-rounded" and "well rounded"; desirable properties for use in concrete.

Ordinarily the stream channel deposits are replenished by material carried by seasonal floods. Overburden is rarely present, but high flood waters may leave silt, clay, and debris covering parts of the deposit. The maximum size of gravel gradually decreases downstream.

Floodplain deposits consist of material deposited on plains bordering the stream by periodic overflow of Cache Creek from its channel. The sediments deposited are normally in the silt and sand size ranges. However, these fine materials (classified as Yolo soil series) mantle usable deposits of sand and gravel, particularly downstream. These sand and gravel deposits are similar to those in the channel and are suitable for use after the overlying silt layers are removed.

Petrographic Properties

The Cache Creek deposit was studied extensively by the U. S. Bureau of Reclamation as a source for the construction of Monticello Dam in the mid 1950's. A comprehensive report on the aggregates, prepared by Klein and Goldman (1958) concluded that gravel of the lower basin deposit is composed chiefly of graywacke-type sandstone (above 60 percent), metamorphosed basic igneous rock (greenstone) (about 15 percent), chert (10 to 18 percent), and quartz veinlet (about 10 percent). Granitic, metavolcanic, and amphibolitic metamorphosed rocks, serpentine, and limestone constitute the remainder. The principal physically unsound rock types are the badly-weathered sandstones, soft serpentines, and fractured quartz veinlets.

Rock particles of the same types mentioned above and in the same general proportions compose the bulk of the sand fraction.

Standard acceptance tests performed by the U. S. Bureau of Reclamation confirmed that the sand and gravel from the lower reaches of Cache Creek were suitable for use in mass concrete structures. Periodic tests by the California Division of Highways indicate that the aggregate produced at the commercial plants meet their specifications for use in concrete.

YOLO COUNTY AGGREGATE INDUSTRY

Commercial Production

Commercial production has centered on the lower reaches of Cache Creek near the towns of Yolo and Madison. In 1976 seven operations were active: three above the Stevens Bridge and four below (Yolo County DPW also operates below Stevens Bridge). The total recorded production from 1915 to 1975 approximates 55 million dollars in value. Since 1970, annual production has risen gradually from 2.0 to 2.7 million tons.

Materials are excavated from the streambed and floodplain by self-loading scrapers and transported to nearby plants. There are seven permanent processing plants in which the sand and gravel is washed and sized. Gravel larger than 1-1/2 in. is crushed to produce smaller sizes, and the sands are washed in screw-type classifiers. Ordinarily, the excavated material is stockpiled near the plant to be processed throughout the year (when high water precludes the use of scrapers in the creek).

The aggregate producers operate under permits from the County (these regulate hours of operation and noise and dust emissions). Only Solano Concrete and Cache Creek Aggregates are constrained by county controls on depth and width of excavation. Other governmental agencies that regulate aggregate operations are the State Reclamation Board, Industrial Safety Board, Department of Fish and Game, and others.

Market

Aggregate produced from Cache Creek is marketed primarily in Yolo and Solano Counties, with a small proportion sold in Sacramento County (primarily sand) and Napa County. Aggregate is sold FOB the plant for use in concrete, base course for roads, or asphaltic mixes for road surfacing or driveways. Since aggregate is a low-cost/high-volume commodity, the limiting market factor is the cost of transportation.

This commodity cannot be transported very far before the cost of transportation exceeds the cost of aggregate at the source. The cost of trucking runs between 10 and 15¢ per ton mile. Thus, a ton of sand, delivered to Vacaville, would cost the average consumer about $2 in hauling charges, while someone in Woodland would pay only $.60 for hauling charges on the same ton.

It is difficult to state an average price per ton of aggregate, since each size and grade commands a separate price, plus there are varying discounts to different categories of buyers (e.g., government agencies, large contractors). However prices at the plant range from about $1.50 to $2.50 per ton.

Remaining Deposits

In 1958 Klein and Goldman estimated that one million cubic yards of aggregate per mile was present in the reach from Esparto to Yolo.

In this study, USDA soil classification maps were used to delineate the aggregate deposits corresponding to riverwash and floodplain soils. In the area from Stevens Bridge to Yolo, there is an estimated 94 million tons of aggregates which would have a life of some 30 to 60 years (this is based on an assumed average depth of 40 ft). Upstream from Stevens Bridge to Capay, there is an estimated 120 million tons available, with a life of 60 to 80 years. It is assumed that in the near future there will be a trend of production and consumption remaining at or slightly below the current annual production rate of 2.7 million tons. Approximately half of the total production (which is obtained from the producers downstream of Stevens Bridge) is marketed in Yolo and Sacramento Counties. The remainder of the production, which goes primarily to Solano and parts of Yolo County is provided from the upstream plants.

Future demand may accelerate for materials in Solano County as a consequence of heavy commercial construction. This demand will probably be met largely by the upstream plants. If so, the deposits in Cache Creek will deplete at a fairly uniform rate throughout its length.

Alternative Sources

Aggregate is obtained from the easily mined and readily accessible channels of the major streams in the Sacramento Valley. The nearest alternative sources to Cache Creek would be the alluvial deposits of the American River, east of Sacramento (approximately 25 miles) or from Colusa (approximately 40 miles). The economics of operating a rock quarry to provide aggregate would not come into play until the sand and gravel was imported from these alternative sources. This is because it costs about $1.70 per ton to drill, blast, and crush rock for aggregate.

The impact on local construction of importing substitute materials would be felt in the increase in the cost of large structures and in the major public works. For the average home buyer an increase of $2 per ton (for additional haul) could mean an increase of approximately $100 in the base price of a new home. However in highway construction, where hundreds of thousands of tons are used, this additional cost would amount to millions of dollars.

Role of Aggregate Industry in Yolo County

The aggregate extraction industry operating in Cache Creek currently employs an estimated 190 to 200 persons who earn estimated annual wages totalling approximately $2.7 million. Employee labor classifications include: machinery operators, mechanics, supervisory/administrative personnel, and truck drivers. The approximate composition of the Yolo County aggregate industry labor force is estimated as follows:

15-16	professional, technical, managers, and kindred workers
29-31	clerical and kindred workers
146-153	craftsmen, foremen, operatives, and kindred workers

A special 1975 census conducted in Yolo County reported total resident employment* of 33,064 persons (principal and secondary wage

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*Note that this term refers to those people who live in Yolo County, regardless of where they may work.

earners).* Principal wage earners amounted to 23,755 persons, countywide. Approximately 10,200 Yolo County residents were employed in the Woodland area, with 7,034 of those being principal wage earners.

Assuming that at least 150 of the total aggregate industry employees live within Yolo County and that all of these employees are the principal wage earners in their families, then the aggregate industry currently operating in Cache Creek provides employment to about 2 percent of the employed Yolo County residents.

Economic statistics reported by the aggregate industry indicate that the companies together pay approximately $142,000 in County property taxes and approximately $370,000 in State sales taxes. Approximately $76,900 of this gets returned to Yolo County in the form of dollars, and much of the remainder comes back in the form of state services and state-funded programs.

Although some information is lacking re: the smaller operators' investments (presumably they were reluctant to report information which they felt might compromise their market position), the industry reports total investments of approximately $6.0 million in capital equipment and facilities and approximately $1.7 million in land holdings. Note that this includes only land which is owned outright (as opposed to leased land).

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*Note that the total population of Yolo County is approximately 100,700. Woodland's population is approximately 25,400.

Section V

DISCUSSION OF IMPACTS

Section V

DISCUSSION OF IMPACTS

The following discussion deals with the two major phenomena which constitute the primary cause of the impacts observed on Cache Creek; i.e., streambed lowering and stream widening (meandering). These are discussed in terms of the factors which cause them, their magnitude in various reaches, and their relationship to the goal of formulating a viable management policy.

STREAMBED LOWERING

The bed of Cache Creek has lowered between the period 1915 and the present time an average of 5 to 15 ft in the reach from approximately 1-1/2 miles upstream of Capay Bridge to an undetermined distance downstream of the town of Yolo. This section of the report will examine the amount of lowering, the volume of material accounted for in the lowering, cause of lowering, consequences of bed lowering, and future consequences of further bed lowering.

Information Base

Information used in the analysis of streambed lowering included various bridge cross-sections provided by Yolo County Department of Public Works (from survey jobs at specific bridges throughout the years 1946-68), U.S. Geological Survey (USGS) topographic map elevation contours (from the 1915-16 maps of the area and the 1952, 53, and 59 7-1/2 minute quadrangles), and survey data on more recent conditions provided by Yolo Engineers and Surveyors, Inc. (YESI). Another important source

of information on the change in elevation of the bed of Cache Creek is provided by USGS stream gaging records at the Yolo stream gaging station, which has been in continuous operation since 1913. The stream gaging information is recorded as depth of the water across the measured channel for various water stage heights. The gage height readings are referenced to mean sea level so that the elevation of the streambed can be calculated from the depth values recorded. The elevation of the streambed was calculated for various representative time periods between January 1913 and the present time. The Yolo gage records show that the streambed tends to lower during periods of high stream flow but recovers again to some common higher level during low flow. This is characteristic of streams such as Cache Creek which have a mobile bed. The higher position of the streambed (the low flow position) was chosen to represent streambed elevation and was plotted vs. time as shown in Figure 5.

Rate of Lowering

In Figure 5, three distinct periods of increased bed lowering are evident, with the changes occurring around 1950 and around 1964. Based on the Yolo gage, the approximate rates of lowering are:

.08 ft/year between 1913 and 1950
.21 ft/year between 1950 and 1964
.67 ft/year between 1964 and present

The amount of streambed lowering within the reach between Capay Bridge and the Yolo gage is shown in Figure 6. Based on the elevation contours plotted on the USGS topographic maps published in 1915-16 and 1952-59, the streambed elevation increased in some reaches and decreased in others during this time interval. In the reach between Capay Dam and Esparto Bridge, no change is recorded on the topographic maps between 1916 and 1959 (the year of the quadrangle map in this reach). However, between Esparto Bridge and a point approximately mid-way between Madison

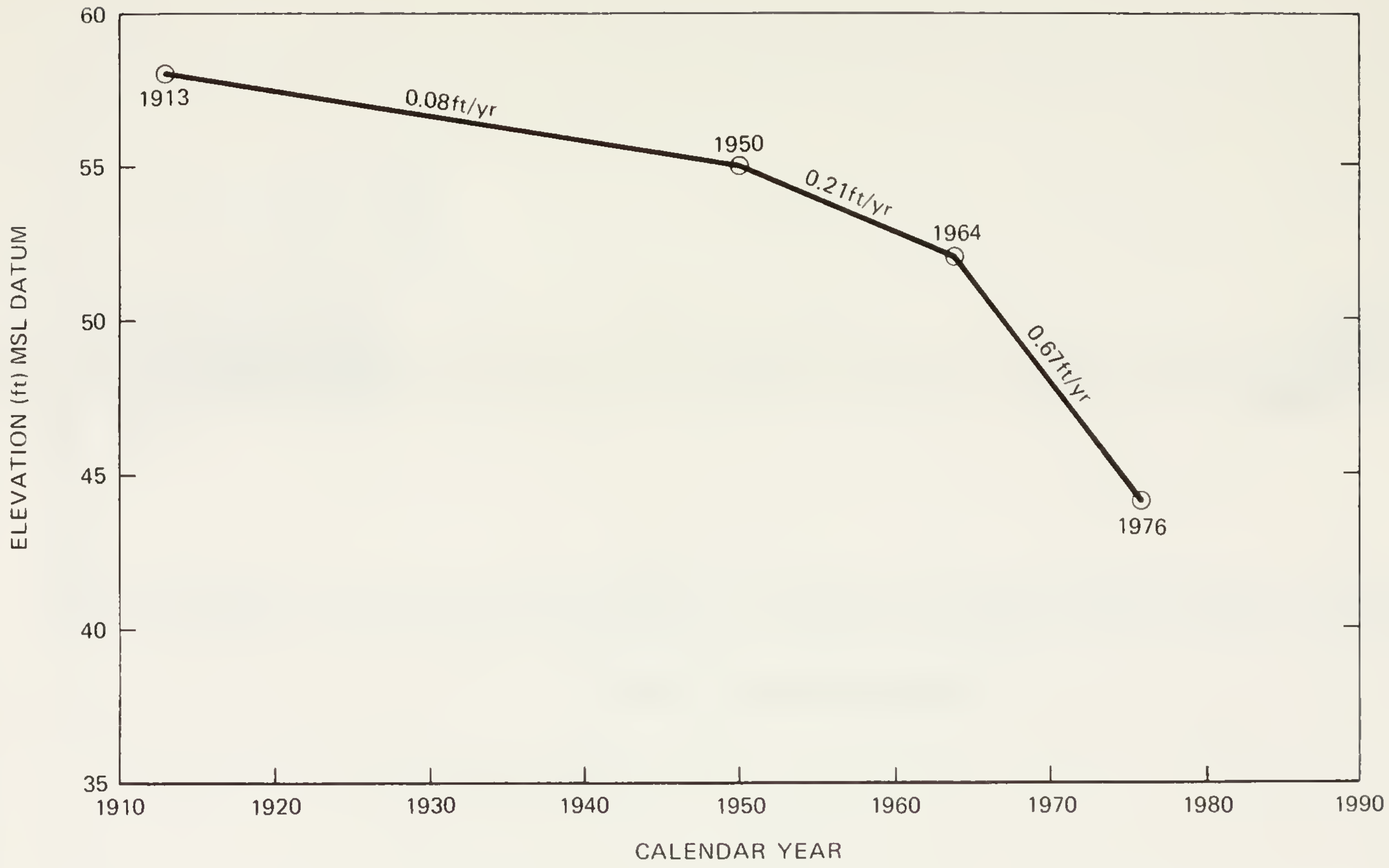


Figure 5. STREAMBED ELEVATION VS TIME AT YOLO STREAM GAGING STATION 1913 TO 1976

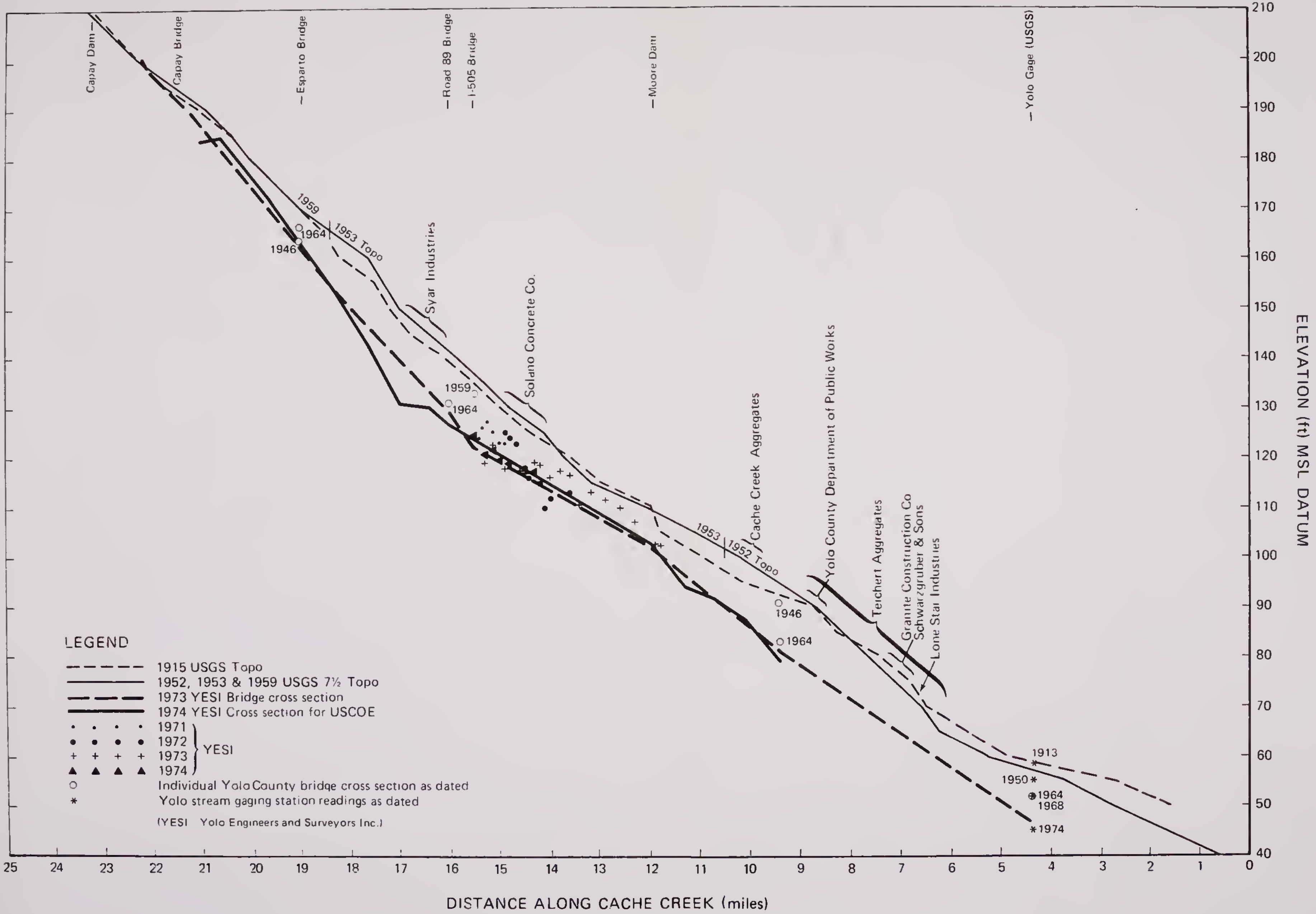


Figure 6. PROFILE OF CACHE CREEK – THALWEG ELEVATIONS 1915 TO 1974

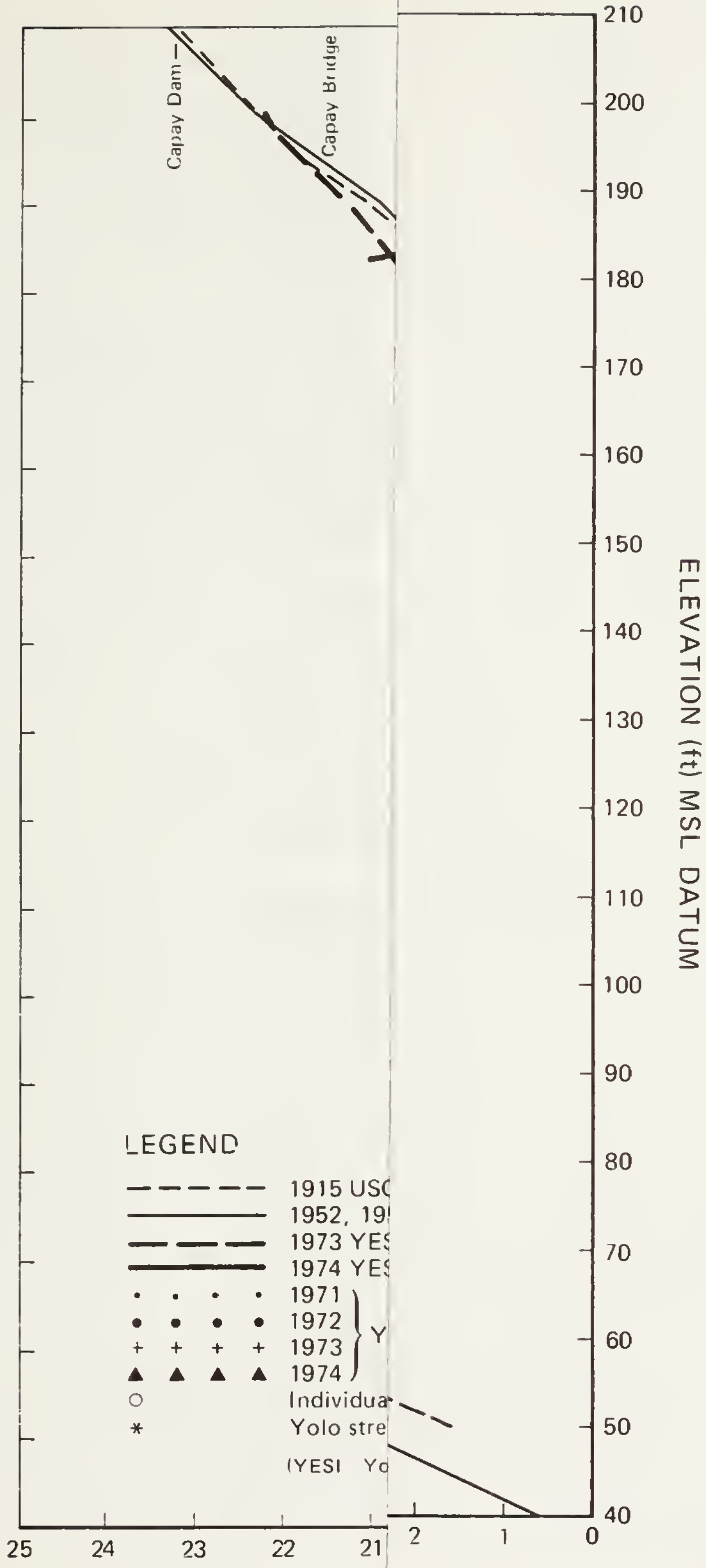


Figure 6. PROFILE OF CACHE CREEK – THALWEG ELEVATIONS 1915 TO 1974

Bridge and Moore Dam the topographic maps suggest that the bed rose an average of about 3 ft between 1916 and 1952 (the year of the quadangle map in this reach). The reach two miles upstream from Moore Dam showed no change in the above time period, but from just downstream of Moore Dam to Stevens Bridge the bed rose an average of about 5 ft. (It is speculated that this rise may have been the result of the failure of Moore Dam between the two time periods which would have resulted in the release of gravel retained upstream of the dam and redistribution by stream action along the downstream reach). In the reach downstream from Stevens Bridge to well below the Yolo gage, the 1916 and 1952 topographic maps show that the bed lowered between 2 and 5 ft.

Since the Yolo gage record suggests that little change occurred between 1950 and years of the most recent USGS topographic maps (1952 to 1959) in the lower reaches of the Cache Creek, we have used the stream profile on these most recent topographic maps as the starting point for calculating bed lowering in Cache Creek. The maps provide the only continuous profile of stream channel elevation in the early 1950s.

The amount of bed lowering between Capay Bridge and downstream of the Yolo gage is shown in Figure 6 which plots the "thalweg" elevation, (i.e., the lowest point in the stream channel). Information from this diagram within specific reaches is as follows:

No change is apparent in the streambed elevation between Capay Dam and a point approximately 1 mile upstream of Capay Bridge. From this point to Capay Bridge and along the reach downstream to Esparto Bridge, the streambed has lowered a progressively greater amount, until at the Esparto Bridge the bed has lowered 8 ft. The reach between the Esparto Bridge and a point 1 mile upstream from Moore Dam has undergone the greatest bed lowering in the upper basin. In this reach the bed lowering ranges from 10 to 19 ft (the 19 ft maximum was recorded between 1952 and the most recent survey in 1974). The reach of Cache Creek

between a point 1 mile upstream of Moore Dam and a mile downstream of Moore Dam has experienced the least bed lowering, averaging about 6 ft. From a mile downstream of Moore Dam to the Yolo gage, bed lowering has increased again, with an average of about 12 ft and a maximum of over 13 ft.

Volume of Aggregate Removed

The amount of material that would have had to be removed to account for the bed lowering observed in Cache Creek was calculated in the following manner:

Aerial photographs taken along Cache Creek in 1939 and again in 1972 were utilized to define the areas of active erosion and deposition along the creek. The 1939 area was used as the upper surface of a volume and the 1972 area the lower surface. The height of the sides of the volume were provided by the amount of bed lowering between 1952-53 and 1972-74, based on the mean stream channel elevation profiles shown in Figure 7. The total volume, which equals the amount of material removed, was determined by summing individual volume calculations for 16 segments along the creek.

The mean stream channel profile indicates that the channel lowered between 3 and 15 feet, with an approximate average change of 9 feet, during the period 1952-74. A comparison between the thalweg profiles and the mean stream channel profiles show that the thalweg is always about 4 feet lower than the mean stream channel for any given year. The mean stream channel elevation profile was used to calculate volume change because it more nearly represents the configuration of the channel over its entire width.

The area of the active creek channel was essentially the same in 1939 and 1972, and the stream channel elevation along most of the creek was about the same in 1939 and 1952-53. Therefore, volume changes in

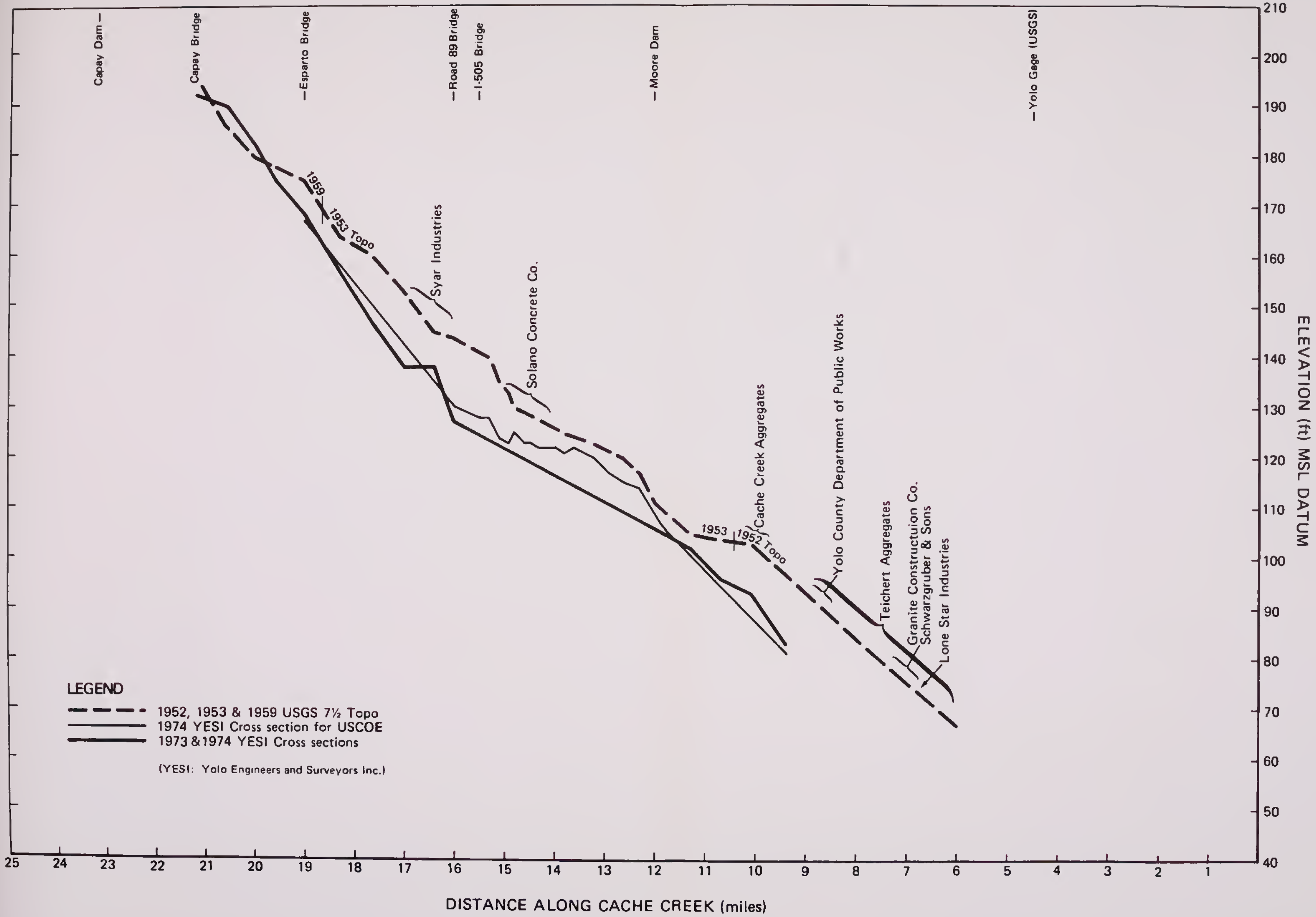
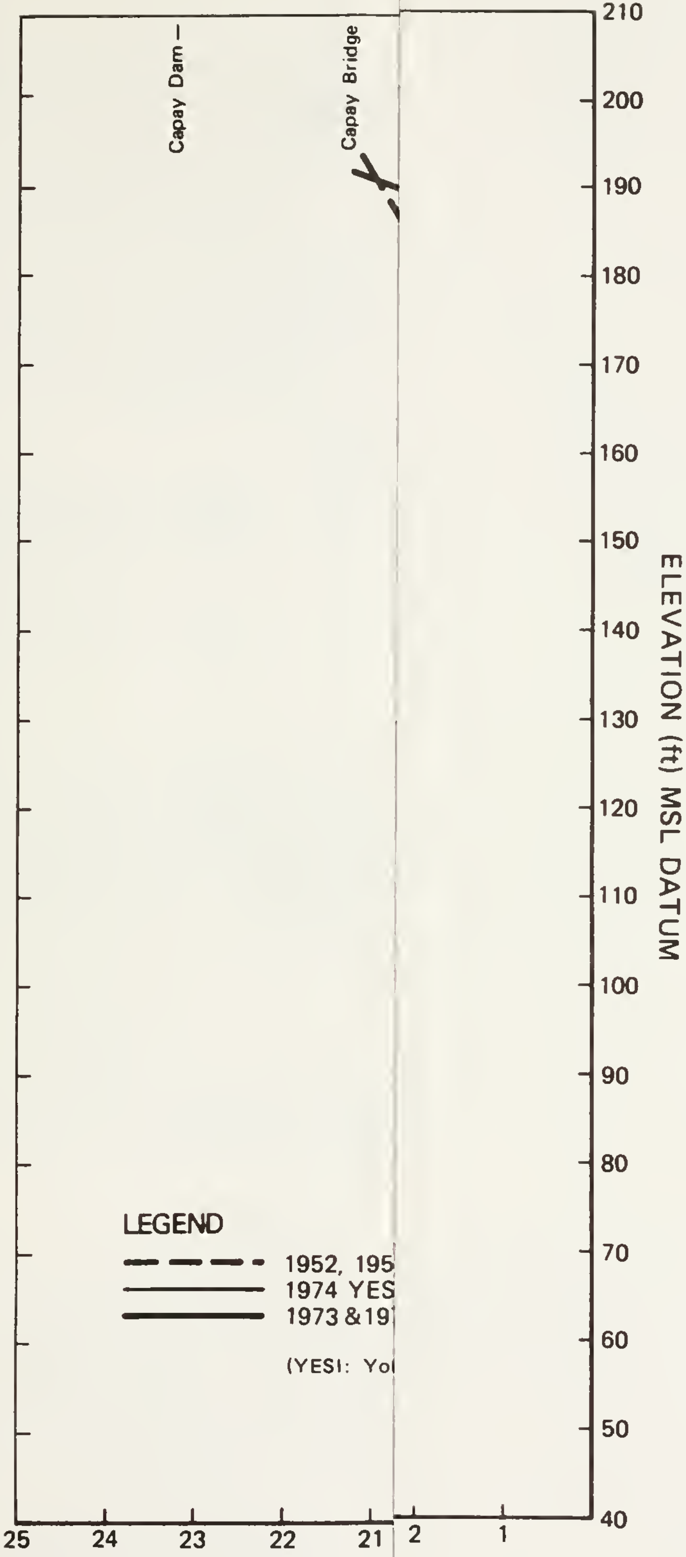


Figure 7. PROFILE OF CACHE CREEK – MEAN STREAM BOTTOM ELEVATIONS 1915 TO 1974



ure 7. PROFILE OF CACHE CREEK –
MEAN STREAM BOTTOM
ELEVATIONS 1915 TO 1974

the creek channel essentially began in the very early 1950s. Since about 1950, a total of 36 million cubic yards or 48 million tons of material must have been removed from the creek channel to account for the observed bed lowering.

If this total volume was removed between 1939 and 1974 at a rate corresponding to bed lowering at the Yolo stream gaging station (Figure 5) the volume changes would be as follows:

Time Period	Years	Million Cubic Yards Per Year	Million Tons Per Year
1939 - 50	11	0.26	0.35
1950 - 64	14	0.72	0.95
1964 - 74	10	2.34	3.1

This rate of volume change (expressed as tons per year) in the channel is shown in Figure 8 together with the yearly aggregate sales in tons per year, as reported by the aggregate industry. The implications of the similarity between these two plots is discussed below.

Cause of Bed Lowering

The two main causes of streambed lowering: (listed in order of importance) are: aggregate extraction operations and other influences of man.

Aggregate Extraction Operations. Prior to about 1950, the aggregate industry was producing on the average of about 300,000 tons per year (which is approximately equivalent to the long-term average bed load which would be transported through the Cache Creek system under natural conditions). From 1951 until 1957, the average rate of aggregate production was approximately 900,000 tons per year; a considerable increase brought on by the post-war construction boom and construction of

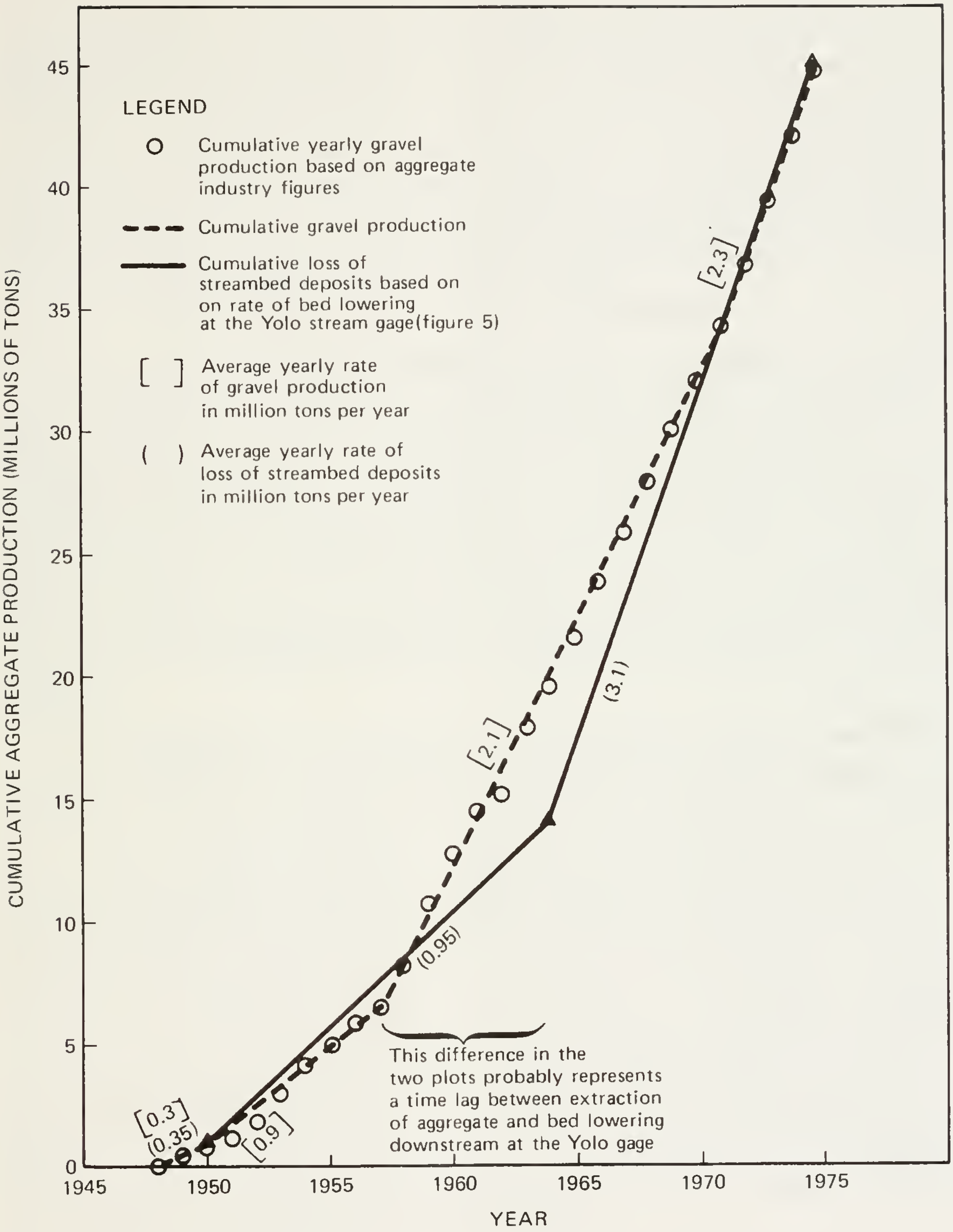


Figure 8. AGGREGATE PRODUCTION VS STREAMBED LOWERING

Monticello Dam. From 1957 to 1970, aggregate extraction increased to approximately 2 million tons per year and increased again from 1970 to 1975 to 2.3 million tons per year. This latter rate is believed to be continuing at the present time and is expected to decline only moderately in the future. The similarity between the plot of volume change represented by bed lowering and the plot of aggregate production (Figure 8) is not coincidental. It is a clear indication that the extraction of gravel is the main cause of bed lowering in Cache Creek.

The annual extraction of gravel since 1950 is between three and ten times greater than the natural replenishment of gravel over the long term. Clearly then, the extraction of gravel can only result in a lowering and widening of the stream bed. The amount of lowering is most pronounced in and just upstream from the reaches where the gravel has been extracted. The amount of bed lowering decreases both upstream and downstream from these extraction locations. These are additional indications that the aggregate industry is primarily responsible for bed lowering.

The lowering of the stream bed in areas where no extraction is or has been conducted in the past can be explained as being a secondary result of the redistribution of bed material by Cache Creek in response to a local streambed lowering. This redistribution occurs when the material moves from the upstream reach downstream to fill in the low areas created by extraction. The similar observed bed lowering downstream of the aggregate operations is explained as a result of erosion of the bed by a stream now deprived of its bed load through deposition in the area of active extraction. The gravel extraction creates an artificially gentle gradient in the channel in which the stream can deposit its bed load. The stream then has increased capacity to erode its channel as it enters the steeper reach downstream, because it has a lower than normal suspended load and bed load.

The two plots shown in Figure 8 do not exactly match during the years from 1958 to 1964. This may be the result of the increased rate of gravel extraction and decreased flood flow. Without substantial stream flow in Cache Creek there would be a lag in the erosion (and thus bed lowering) downstream of the aggregate operations at the Yolo gage. However, by 1964 the stream flow readjustments had begun to catch up to extractions, and the two plots began to converge and became coincident again after 1971.

Other Man-Induced Causes. The difference in the streambed elevation both upstream and downstream from Moore Dam (as seen by comparing the 1916 and 1952 topographic maps) shows that the old Moore Dam influenced the bed of Cache Creek. This influence was shown by a build up of gravel behind the dam and a substantial lowering of the streambed just downstream of the dam. It is likely that the 1916 profile really represents a case where the old Moore Dam prevented the downstream movement of bed load, thus starving the channel downstream from the dam and causing it to lower through channel erosion. The 1952 topographic map (drawn after Moore Dam failed) shows the bed to have lowered upstream of the dam and raised approximately 5 ft downstream of the dam. The stream simply resumed its original pre-1916 dam profile.

Nearly every activity of man in Cache Creek has had some influence on the stream regime. There are reports that the original riparian vegetation which was abundant along Cache Creek was removed during the late 1930s by WPA work crews. The vegetation removal was an attempt to increase flood flow in the channel. This may well have had the effect of allowing greater (and thus more erosive) flows to pass down through the channel than had been possible previously under riparian vegetation conditions. The construction of bridges with piers in the stream channels causes local scour around the piers as a result of local turbulence

during flood flow. There may also be some local upstream and downstream influences on the elevation of the channel. However, these bridges have had no significant influence on bed lowering of the magnitude observed.

Of the various man-induced factors other than gravel extraction that have influenced bed lowering, perhaps the most profound is the flood control activities that have gone on along Cache Creek since agriculture first came to Yolo County. (e.g., channelization and levee construction to prevent Cache Creek from flooding over its banks). This has the effect of restricting high flood flows to the confines of an artificially-leveed channel. This may well have had some influence on increasing erosion during periods of high flow thus contributing to streambed lowering. The Yolo gage record clearly shows that the bed is scoured during high flow and backfilled again as the flow diminishes. The Yolo gage record also shows that after 1968 the fluctuation between high flow bed elevation and low flow bed elevation substantially increased. The percentage of bed lowering due to increased flood flow channelization is not known, but is probably only a small percentage of the effect of aggregate extraction.

The more important consequences of bed lowering along Cache Creek between Capay Dam and Yolo include the undermining of bridges, the lowering of the spring high groundwater levels in the upper basin, and the effects on recharge. These consequences are discussed below.

Effects on Bridges

All of the bridges between Capay and Yolo have been undermined to some degree by streambed lowering. The bridges are typically built with several central piers in the stream channel that are founded on piles driven deep into the subsurface materials. The piles were typically

constructed with a concrete cap somewhat below the elevation of the stream channel (so the bed material can provide some erosion protection for the piles). The streambed lowering at most bridge locations has exposed previously-buried sections of the pile cap. Where the bed lowering has been extreme (such as at Stevens Bridge and Madison Bridge) several feet of the piles themselves have been exposed. Such undermining seriously jeopardizes the stability of the bridge and leaves the piles exposed to corrosion or decay and erosion.

The older bridges (such as the Madison and Stevens Bridge) are most seriously effected because they have experienced the greatest exposure of pile caps and piles. More recently constructed bridges (such as I-505, just downstream from Madison Bridge) are experiencing local scour partly as a result of bed lowering. The proposed new construction at the I-5 crossing is now undergoing design evaluation, because the amount of bed lowering at that location in the future is not presently known and the design implications are considerable.

The Esparto Bridge is effected only on one end where the thalweg (deepest portion of the stream channel) has eroded deeply in the vicinity of the southern piers. This bridge does not seem to be in jeopardy from a safety standpoint, however. The Capay bridge is essentially unaffected, since bed lowering there has amounted to only about 3 ft.

Effects on Groundwater Resources

The phenomenon of streambed lowering affects groundwater resources by reducing the storage capacity of the upper groundwater basin and by affecting recharge.

Effects on Storage. The lowering of the streambed of Cache Creek between Esparto Bridge and Moore Dam has had the effect of lowering the elevation of the water table during the time of the spring high by an average of approximately 10 ft over nearly the entire upper Cache Creek groundwater basin. An explanation of this phenomena follows.

If a series of hypothetical cross-section lines are drawn at right angles to the course of Cache Creek, then the bed of the creek is always the lowest point along these lines. That is, the creek channel is a natural drainage way for groundwater when the water table is higher than the channel. The cross-sections in Figure 9 (section along the Madison-Dunnigan Road) and Figure 10 show that the streambed is currently in contact with the upper gravel unit in the alluvium. This has the effect of allowing groundwater to move from the stream into the ground (the upper gravel unit) or from the ground into the stream, depending on the relative elevations of the water surface in either place.

The reach of Cache Creek between Esparto Bridge and Moore Dam has historically been an area of high water table during all portions of most years, even during the last 10 years of overdraft conditions. During the spring, the water table reaches its highest level of the year as a result of recharge of flow in Cache Creek during the rainy season. The fact that the water table is higher than the streambed elevation during the spring high can be seen by comparing the elevation of the water level and the elevation of the thalweg of Cache Creek (i.e., the lowest point along the thread of the stream) in 1953 and 1974 in the reach between Esparto Bridge and Moore Dam. During 1953 the water table

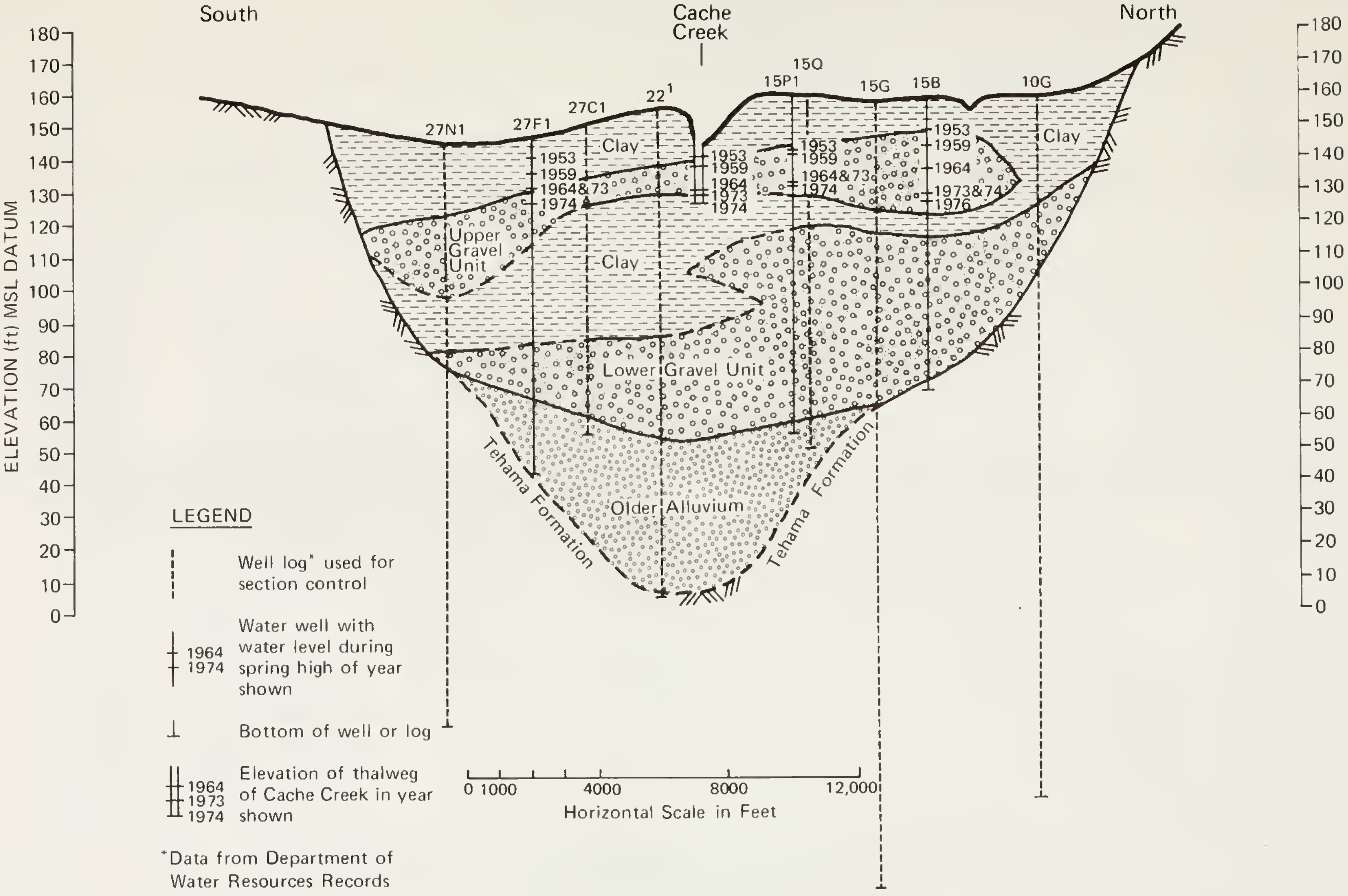
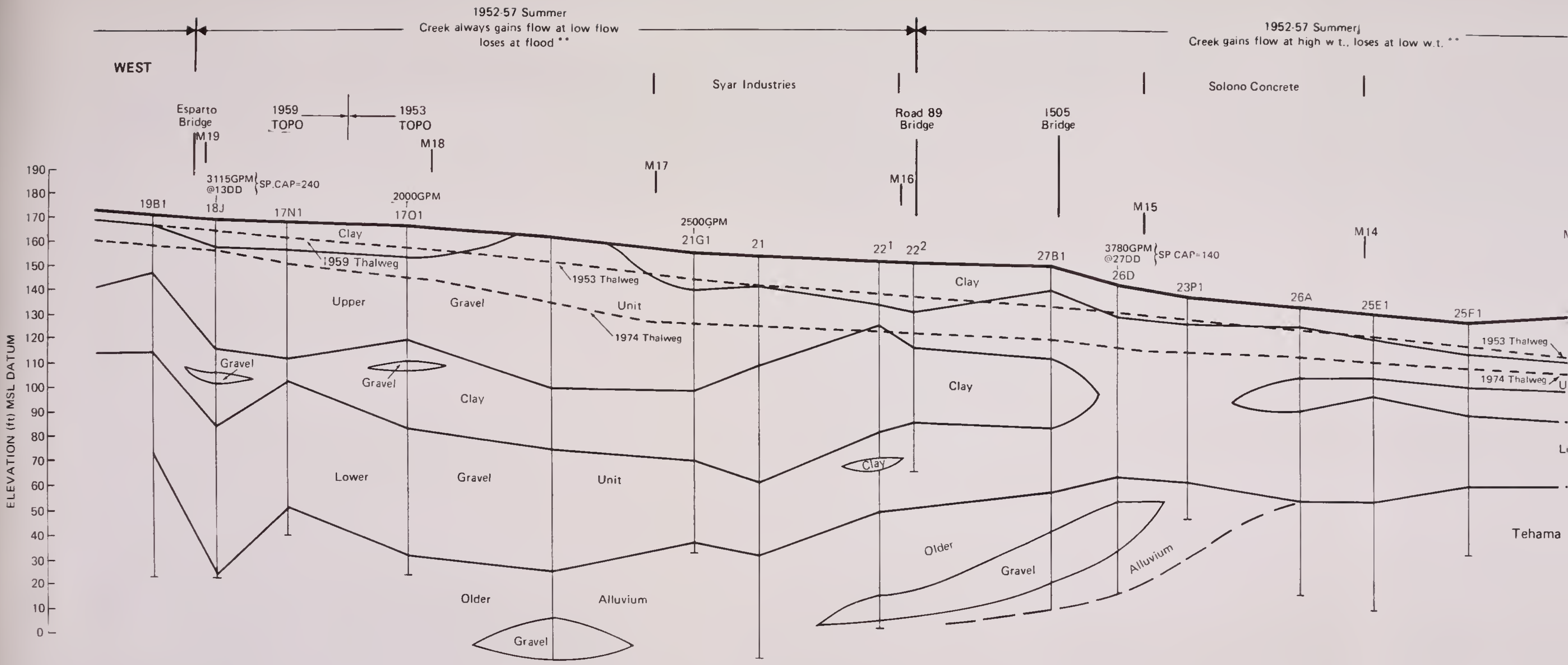


Figure 9. GEOLOGIC SECTION ACROSS CACHE CREEK ALONG ROAD 89


1952-57 Summer
Creek always gains flow at low flow
loses at flood **
1952-57 Summer
Creek gains flow at high w.t., loses at low w.t. **
WEST
Syar Industries
Solono Concrete
Esparto
Bridge
M19
1959
TOPO
1953
TOPO
M18
M17
Road 89
Bridge
M16
1505
Bridge
M15
M14
3115GPM
@13DD
SP.CAP=240
2000GPM
2500GPM
3780GPM
@27DD
SP CAP=140
19B1
18J
17N1
17O1
21G1
21
22¹
22²
27B1
26D
23P1
26A
25E1
25F1
Clay
1959 Thalweg
1953 Thalweg
1974 Thalweg
Upper
Gravel
Unit
Clay
Gravel
Gravel
Clay
Clay
Lower
Gravel
Unit
Clay
Older
Gravel
Alluvium
Older
Alluvium
Gravel
1953 Thalweg
1974 Thalweg
Tehama
ELEVATION (ft) MSL DATUM
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

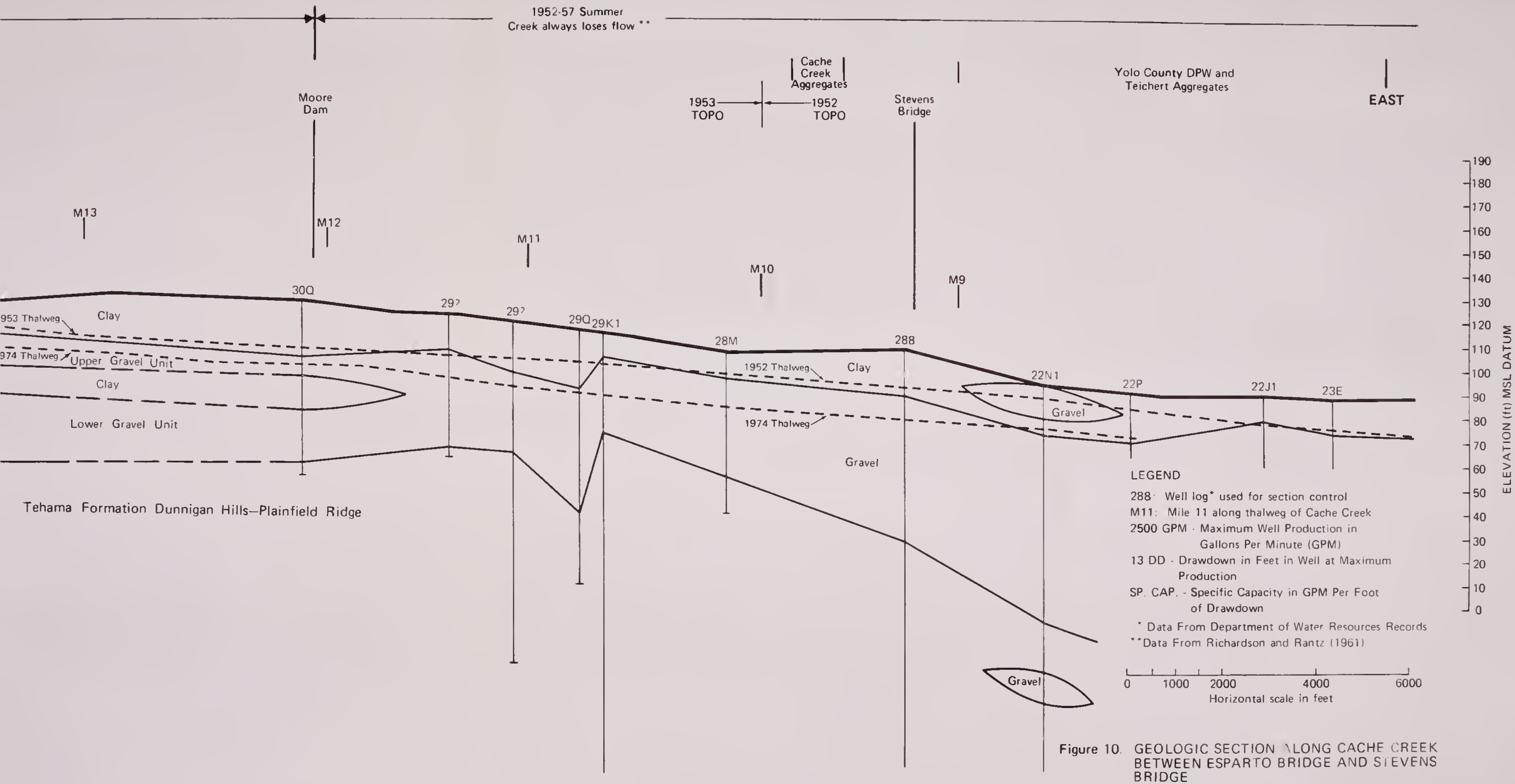

1952-57 Summer
Creek always loses flow **
Cache Creek Aggregates
Moore Dam
1953 TOPO
1952 TOPO
Stevens Bridge
Yolo County DPW and Teichert Aggregates
EAST
M13
M12
M11
M10
M9
30Q
29?
29?
29Q
29K1
28M
288
22N1
22P
22J1
23E
953 Thalweg
974 Thalweg
Clay
Upper Gravel Unit
Clay
Lower Gravel Unit
1952 Thalweg
Clay
1974 Thalweg
Gravel
Gravel
Gravel
Tehama Formation Dunnigan Hills—Plainfield Ridge
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ELEVATION (ft) MSL DATUM
LEGEND
288 · Well log* used for section control
M11: Mile 11 along thalweg of Cache Creek
2500 GPM · Maximum Well Production in Gallons Per Minute (GPM)
13 DD · Drawdown in Feet in Well at Maximum Production
SP. CAP. · Specific Capacity in GPM Per Foot of Drawdown
* Data From Department of Water Resources Records
**Data From Richardson and Rantz (1961)
0
1000
2000
4000
6000
Horizontal scale in feet

Figure 10. GEOLOGIC SECTION ALONG CACHE CREEK BETWEEN ESPARTO BRIDGE AND STEVENS BRIDGE

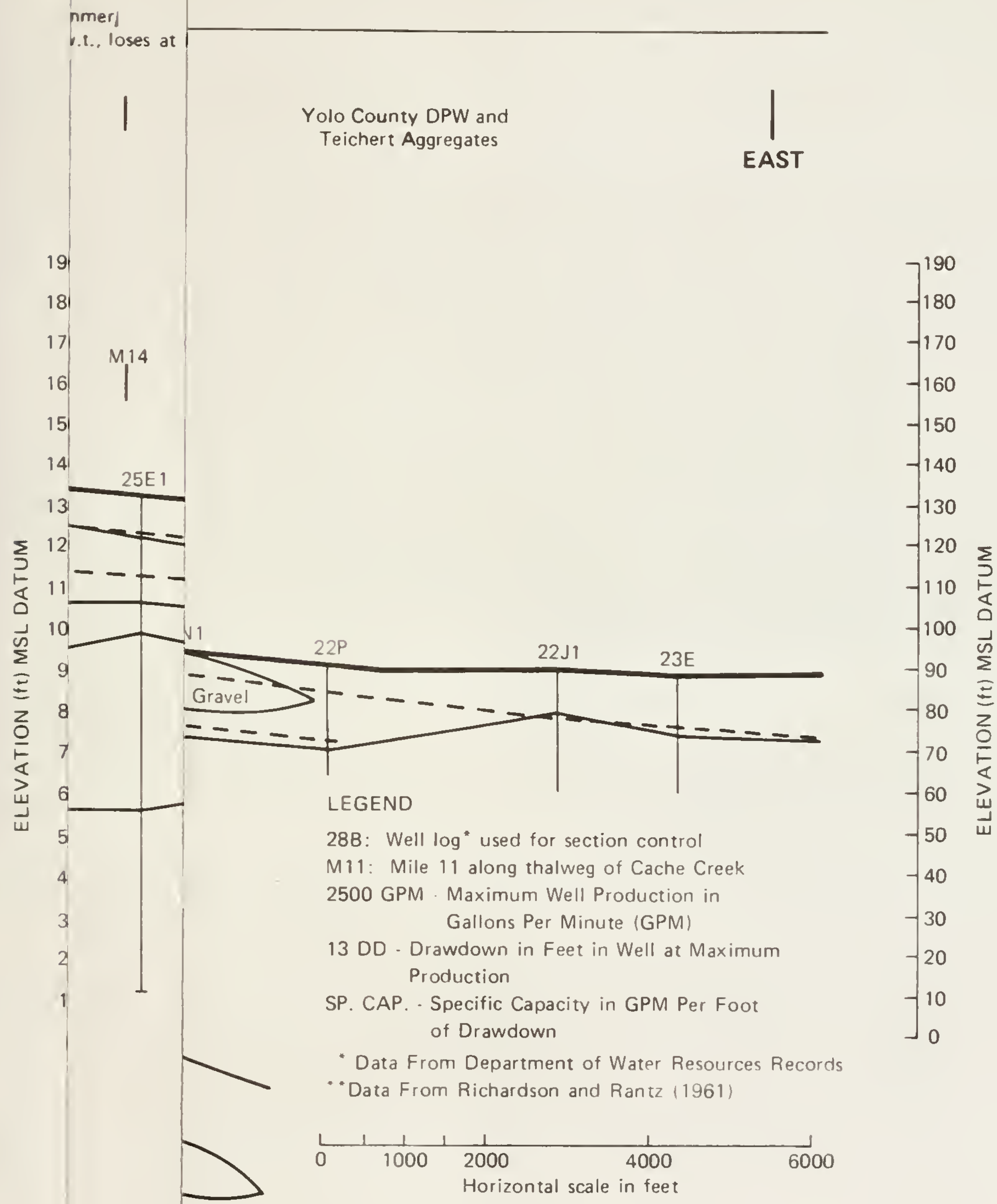

nmerj
.t., loses at
Yolo County DPW and
Teichert Aggregates
EAST
M14
25E1
22P
22J1
23E
Gravel
ELEVATION (ft) MSL DATUM
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
LEGEND
28B: Well log* used for section control
M11: Mile 11 along thalweg of Cache Creek
2500 GPM - Maximum Well Production in Gallons Per Minute (GPM)
13 DD - Drawdown in Feet in Well at Maximum Production
SP. CAP. - Specific Capacity in GPM Per Foot of Drawdown
* Data From Department of Water Resources Records
**Data From Richardson and Rantz (1961)
0
1000
2000
4000
6000
Horizontal scale in feet

Figure 10. GEOLOGIC SECTION ALONG CACHE CREEK BETWEEN ESPARTO BRIDGE AND STEVENS BRIDGE

was relatively high during all portions of the year. The 1974 period corresponds to a low water table condition during the overdraft years. During the spring high in both 1953 and 1974, the groundwater level rose to an elevation higher than the streambed, both north and south of the creek channel. The result of this was that groundwater was moving toward the creek to support surface flow during the spring high. In 1974, after the elevation of the streambed had lowered by approximately 10 ft, the water table during the spring high was also approximately 10 ft lower. The change in elevation of the water table and the thalweg of Cache Creek between the Spring of 1953 and 1974 is shown in Figure 11. The lowering of spring groundwater levels in response to progressive bed lowering is shown in Figure 9 (section along Road 89). This is clear evidence that the lowering of the streambed lowers the water table during the spring high period.

The same effect of a lowered spring high water table is shown in the hydrographs of selected wells near Cache Creek, Figures 12, 13, 14, and 15. These hydrographs show the yearly fluctuation of the spring high and fall low, in addition to the elevation of the streambed at the closest proximity to the well. It can be seen that the spring high positions generally correspond to the elevation of the streambed, again reinforcing our conclusion that the spring water level cannot reach its historic high at the present time because of the lowered streambed.

All of this evidence supports our conclusion that the water table during the spring high has been lowered over at least a 30 square mile area in the northern portion of the upper Cache Creek groundwater basin by an amount approximately equal to the amount of streambed lowering (or approximately 10 ft). This amounts to a loss in storage equal to the storage capacity of a 10-ft thick horizontal slice of the aquifer in the portion of the upper groundwater basin affected.

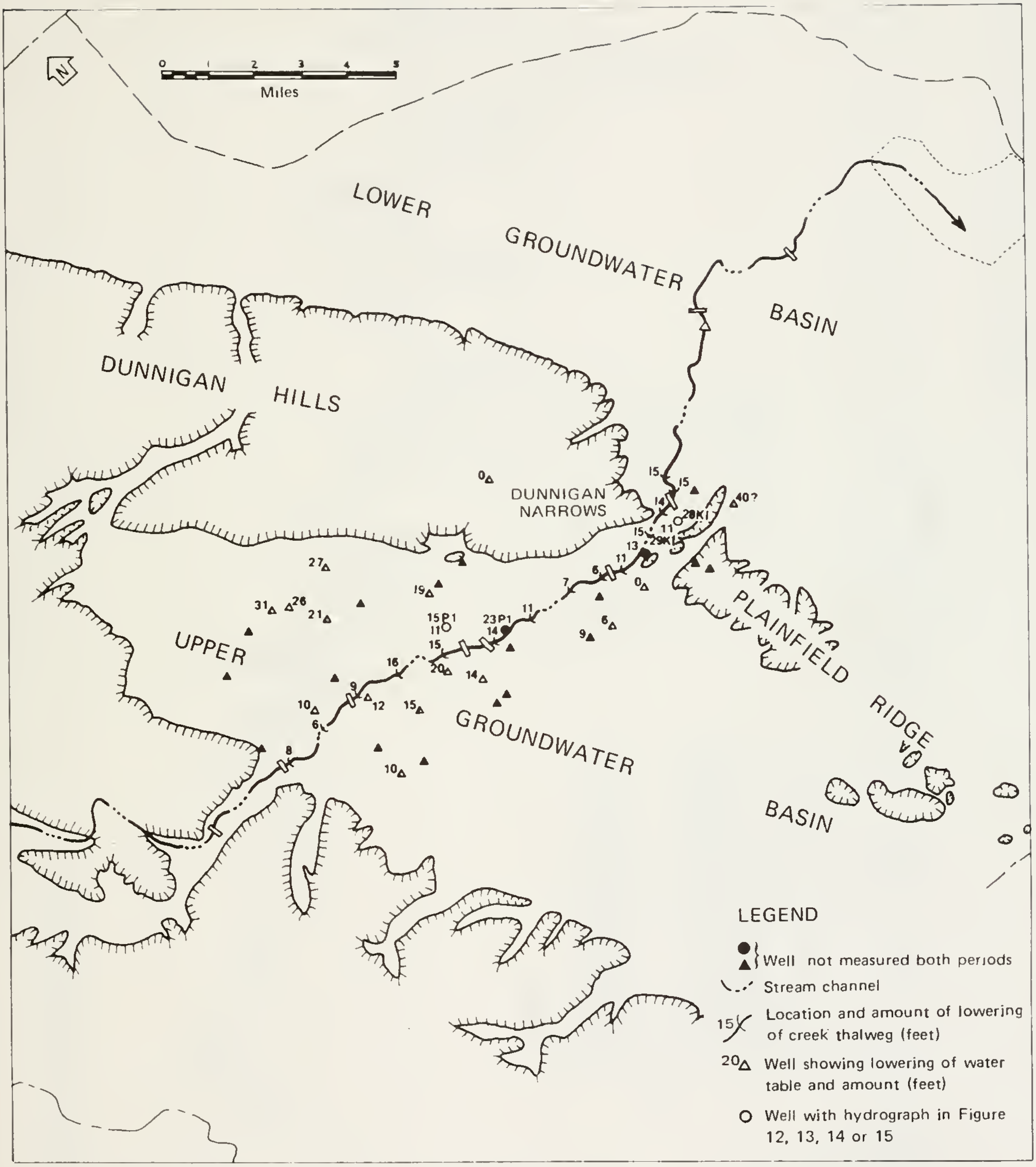

0 1 2 3 4 5
Miles
N
LOWER GROUNDWATER BASIN
DUNNIGAN HILLS
DUNNIGAN NARROWS
PLAINFIELD RIDGE
UPPER GROUNDWATER BASIN
15P1
23P1
28K1
29K1
40?
LEGEND
Well not measured both periods
Stream channel
15 Location and amount of lowering of creek thalweg (feet)
20 Well showing lowering of water table and amount (feet)
Well with hydrograph in Figure 12, 13, 14 or 15

Figure 11. LOWERING OF ELEVATION OF THALWEG AND GROUNDWATER TABLE – SPRING 1953 TO SPRING 1974

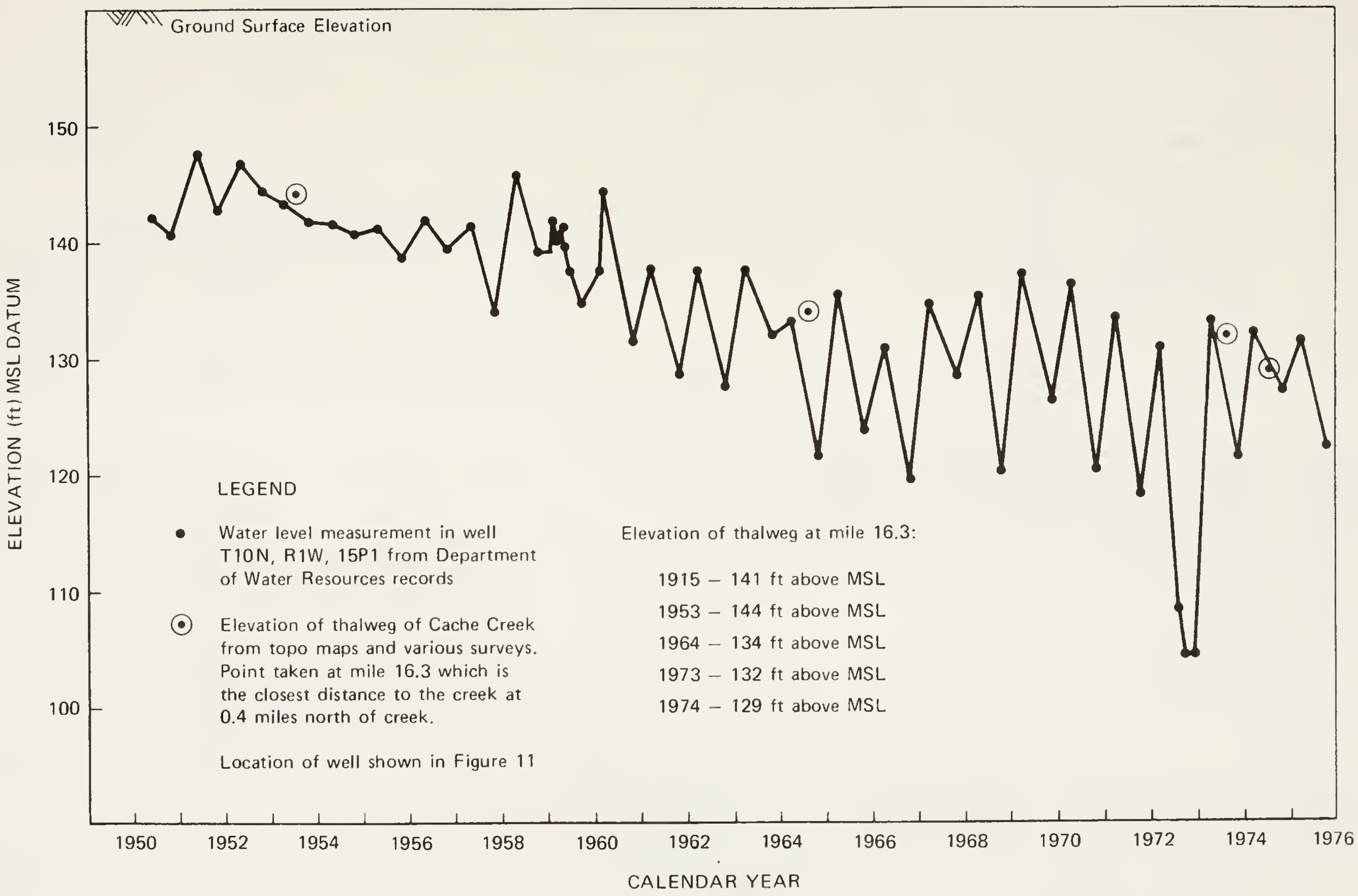


Figure 12. HYDROGRAPH OF WELL 15P1

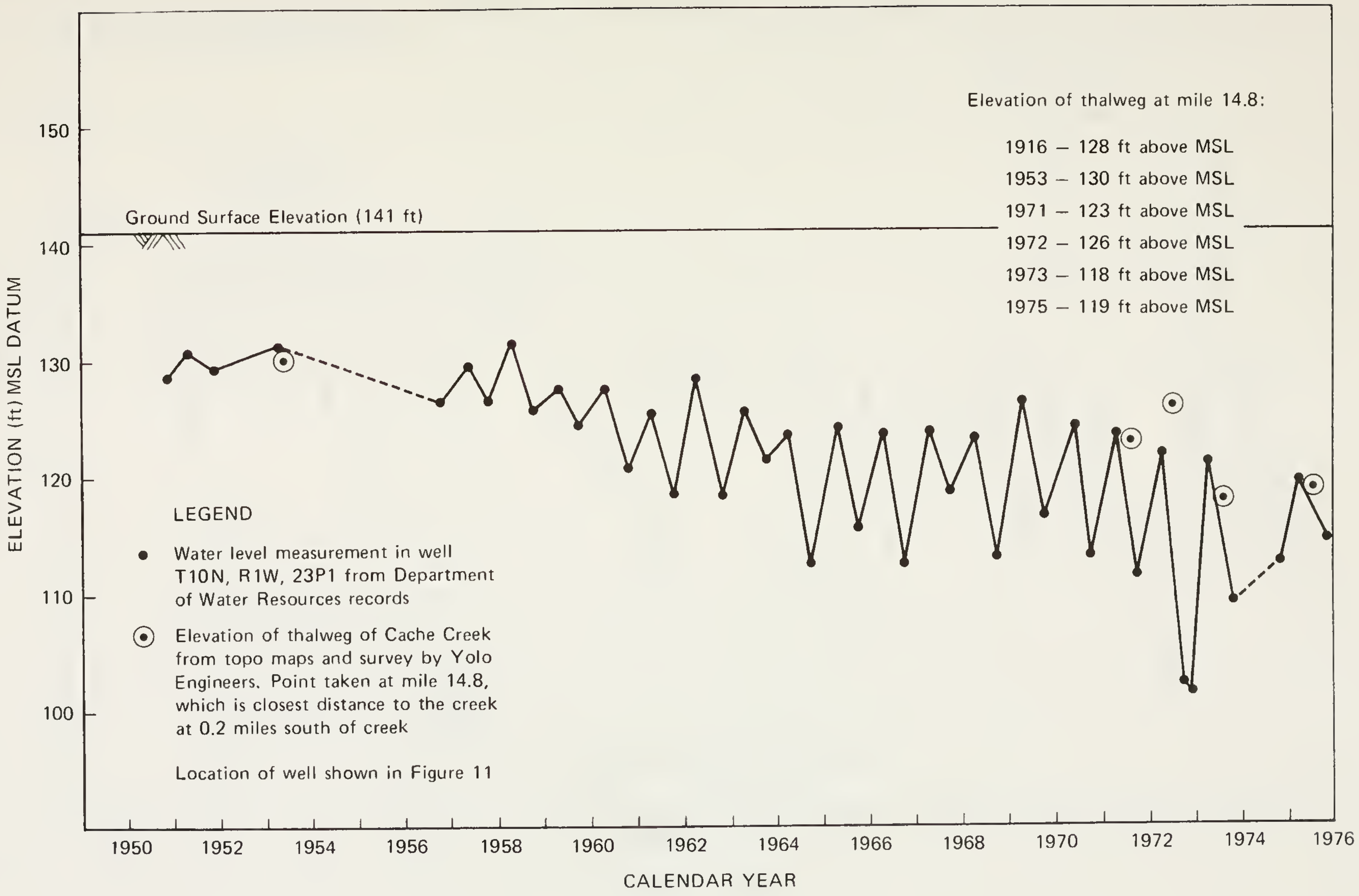


Figure 13. HYDROGRAPH OF WELL 23P1

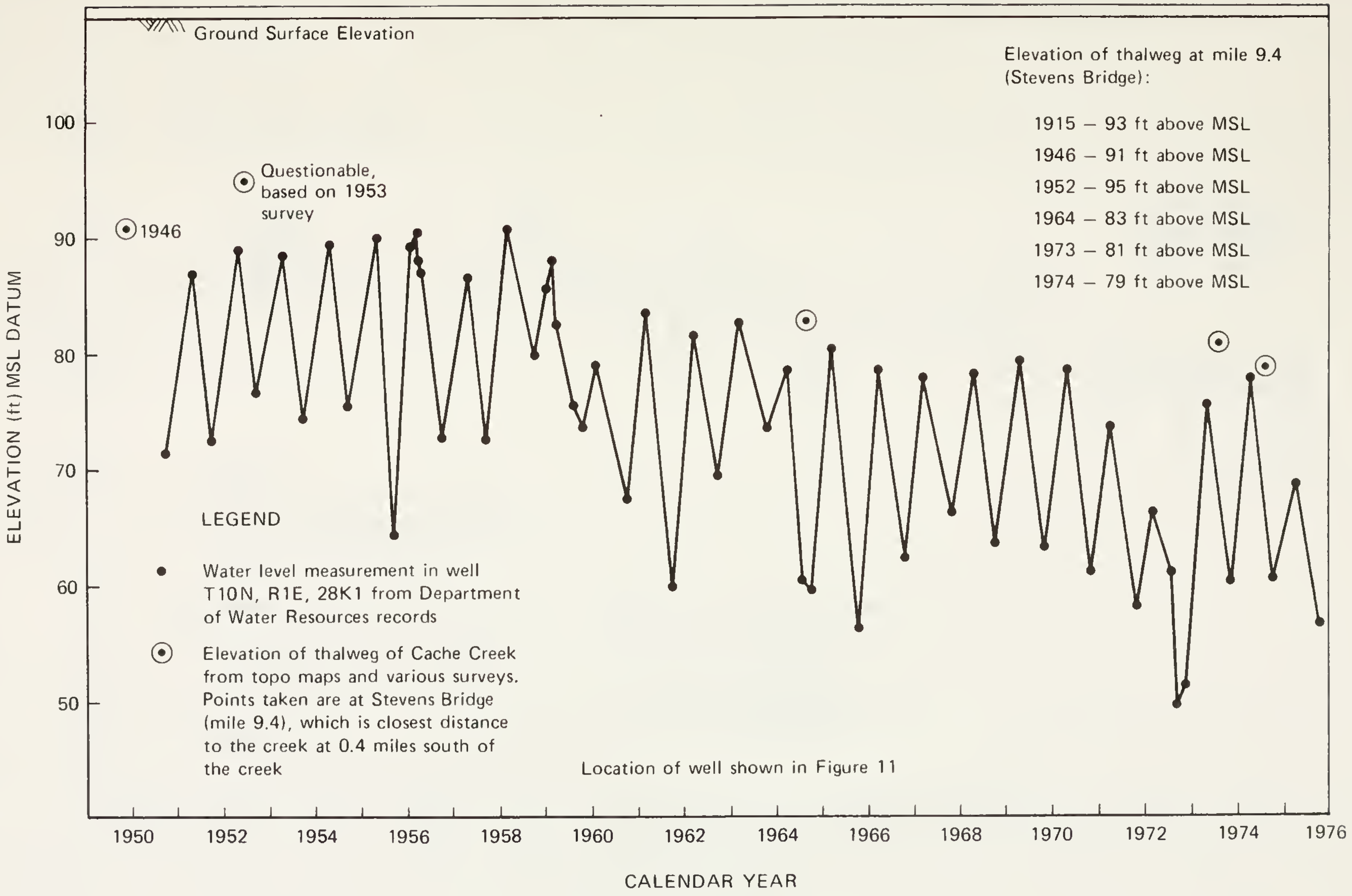
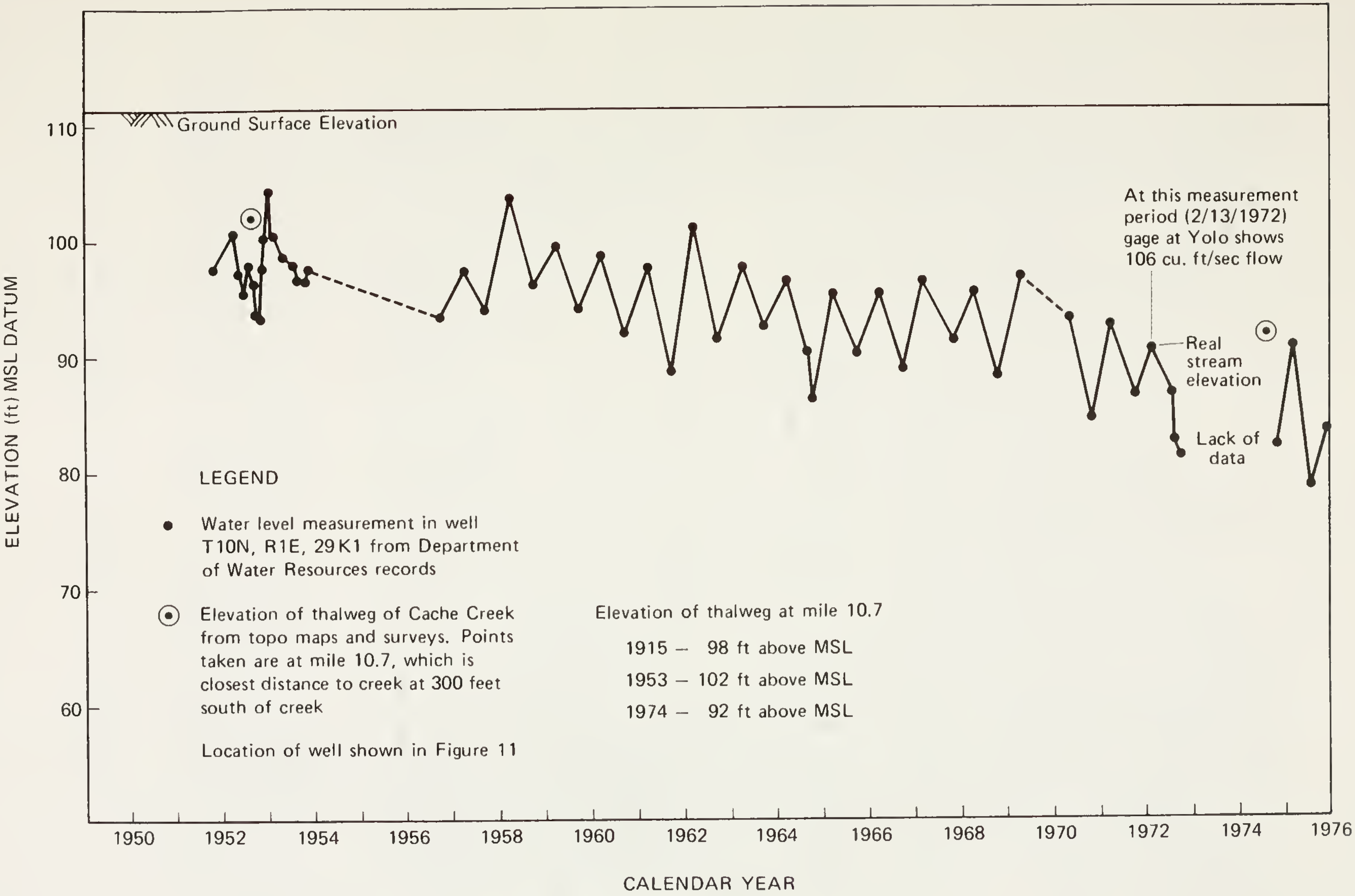


Figure 14. HYDROGRAPH OF WELL 28K1



At this measurement period (2/13/1972) gage at Yolo shows 106 cu. ft/sec flow

LEGEND

- ● Water level measurement in well T10N, R1E, 29K1 from Department of Water Resources records
- ⊙ Elevation of thalweg of Cache Creek from topo maps and surveys. Points taken are at mile 10.7, which is closest distance to creek at 300 feet south of creek

Location of well shown in Figure 11

Elevation of thalweg at mile 10.7

1915 – 98 ft above MSL
1953 – 102 ft above MSL
1974 – 92 ft above MSL

Figure 15. HYDROGRAPH OF WELL 29K1

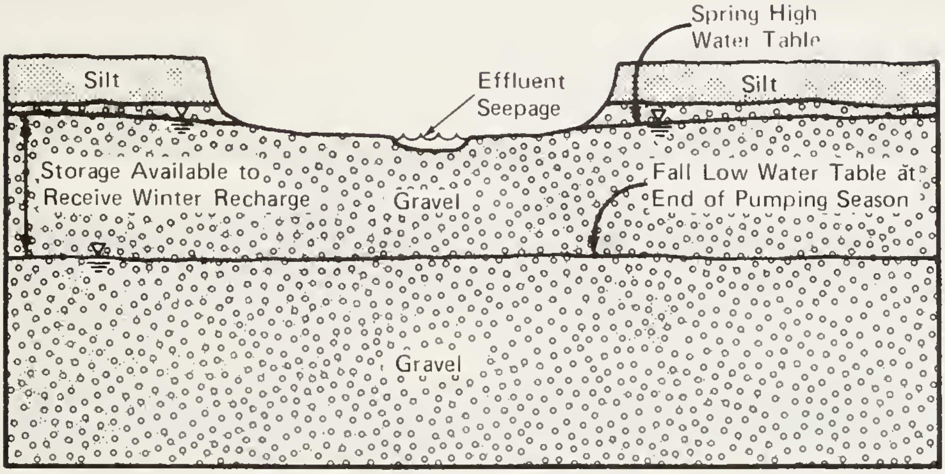
Since the affected area of the upper basin is at least 30 sq miles and if we assume that the specific yield of the upper 20-100 ft of alluvium is 8.9 percent (Scott, et al, 1975), the loss in storage equals approximately 17,000 acre ft, as a conservative estimate. If we assume, as an analysis of well logs suggests (Figures 9 and 10), that the area of change occurs primarily in gravel, then a specific yield of 20 percent is more appropriate and the resulting calculation of storage loss equals approximately 38,000 acre ft, for an upper bound estimate.

The effect of loss in storage is illustrated in Figure 16 and is discussed as follows. The upper groundwater basin cannot fill to its former high position, therefore, during all portions of the year, less groundwater is present in the basin to draw upon during the summer and fall pumping season. Furthermore, the saturated thickness of the aquifer has decreased, which reduces the transmissivity of the aquifer. This has the effect of decreasing the yields of wells slightly and decreasing the quantity of groundwater that moves through the alluvial aquifer system under the same head as during periods before the streambed lowered.

Since groundwater in the upper basin moves into the lower basin through subsurface underflow, the reduced transmissivity (due to reduced saturated thickness of the alluvial aquifers) reduces the amount of groundwater moving into the lower basin during spring high water table. This movement occurs primarily through narrow gaps cut by old channels of Cache Creek through the Plainfield Ridge which are now backfilled with permeable gravel.

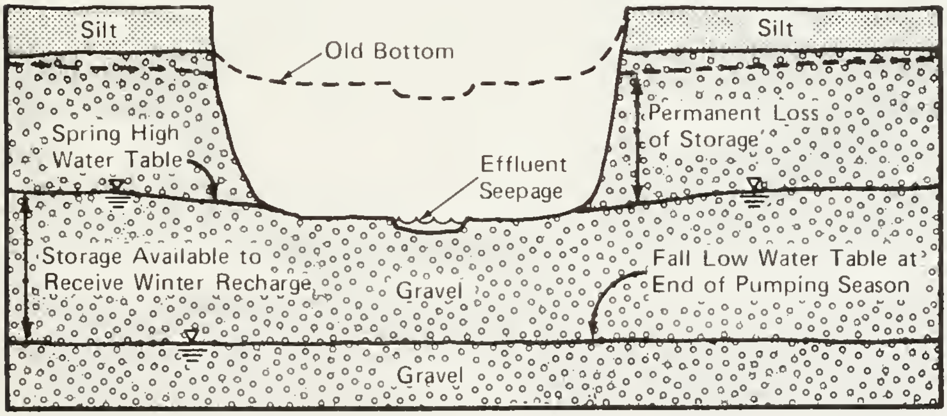
The concept of lost storage can be illustrated as follows. Picture a teacup filled with tea to the brim. If a chip were knocked out say 1/2 inch below the rim, the tea would naturally drain out until the tea level reaches the bottom of the chip. The teacup corresponds to the

Actual Conditions Between Esparto Bridge and Moore Dam



CONDITION 1, Early 1950's:

Spring water table is higher than the creek bed which results in the movement of groundwater into the creek channel to support surface flow. After the pumping season, the fall water table is below the creek bed which provides available storage for recharge of winter flow.



CONDITION 2, Present Time:

Creek bed has lowered to where spring high water table intercepts it at a lower elevation. Since the creek acts as a drain, it prevents the water table from rising to the Condition 1 spring high water table position. This results in a permanent loss of storage equal to the amount of creek bed lowering.

Figure 16. INFLUENCE OF STREAMBED LOWERING ON LOSS OF GROUNDWATER STORAGE DURING SPRING HIGH WATER TABLE

groundwater basin; the teacup brim corresponds to the streambed before lowering; and the bottom of the chip corresponds to the lowered streambed. No matter how much more tea is poured into the cup, within a short period it will drain out again to the level of the chip. The result is that one always has less than a full cup of tea to quench one's thirst. To carry the analogy to Yolo County, the farmers now have less groundwater in the upper groundwater basin to satisfy an agricultural thirst.

Effects on Recharge. The practical significance of streambed lowering effects on recharge is not as clear as the effect on storage capacity. Scott, et al (1975) suggests that during the period 1963 to 1972, recharge along Cache Creek has decreased. This is indeed the case if comparison between the period 1953-59 and the period cited above are an indication. In 1953-59 the average annual recharge along Cache Creek was calculated by the Department of Water Resources (1961) to be 34,000 acre ft per year. The department further calculated that this equalled the long term mean recharge for Cache Creek. The Scott report states that average recharge along Cache Creek during the 1963-72 period was 22,400 acre ft per year. This is a clear reduction of approximately 11,000 acre ft per year in the amount of recharge that takes place along Cache Creek. To resolve the question as to whether this is a valid comparison is beyond the scope of this study, as is the establishment of the role which streambed lowering might play in this decrease of recharge.

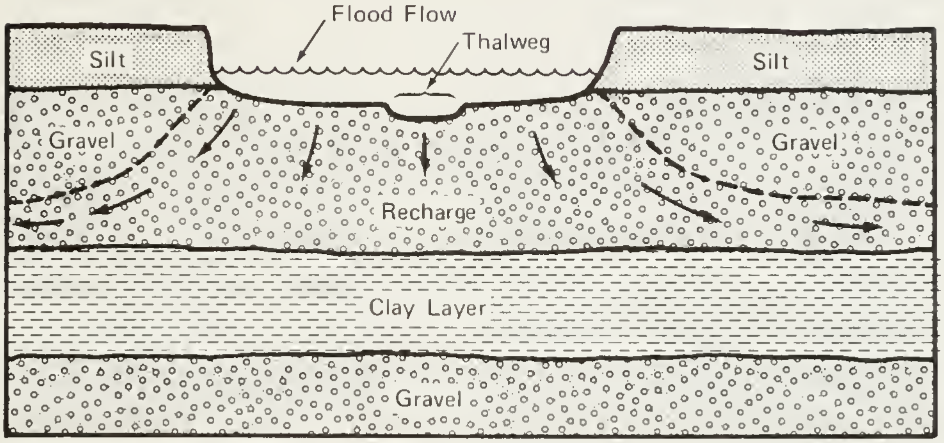
The apparent decrease in recharge along Cache Creek has taken place during a period when the basin has gone into a overdraft condition estimated to have averaged 12,000 acre ft per year between 1963 and 1972 (Scott, et al 1975). It has been suggested that bed lowering has decreased recharge. It could do so in only two ways, given that the basin is now in an overdraft condition in which the water table has declined approximately 25 ft over the upper basin. These two ways include a decrease infiltration capacity along the stream channel and decrease in the

percolation opportunity beneath the stream channel. The following discussion examines each of these in relation to bed lowering.

It is not likely that the infiltration capacity of the streambed itself has changed very much during the period of active aggregate extraction. The reason for this is that the bed has continually lowered, therefore, new layers of underlying channel material (i.e., portions of the upper gravel unit) were being exposed by the aggregate extraction operation. Sedimentation that may have occurred in the channel (as a result of decreased stream gradient or other man-induced factors) has been removed along with the gravel, such that the stream channel is always freshly exposed to infiltration during the extreme flow months. Therefore, any change in infiltration capacity is more likely to be a function of the characteristics of the material that was exposed by excavation rather than a result of sedimentation in the channel. Such a change in infiltration capacity might be brought about by a decrease in the average grain size of gravel in the upper unit as it became exposed in the channel through aggregate extraction. However, such a change would have little effect on recharge.

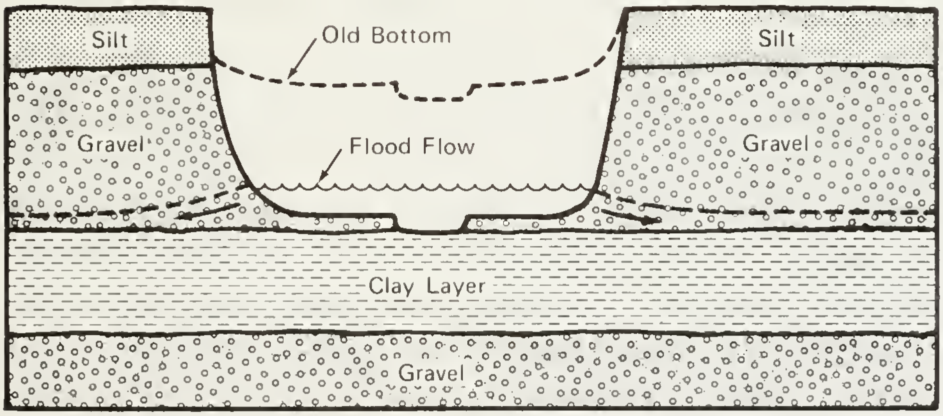
The above line of reasoning suggests that, if recharge has indeed decreased during the study periods mentioned above, the cause is more likely to be a change in the percolation opportunity of the material beneath the stream channel. Such a change could be caused by the presence of clay layers in the alluvial that were fairly near streambed elevation before streambed lowering began and became nearly in contact with the streambed as bed lowering progressed. This concept is illustrated in Figure 17. The presence of such a buried clay layer beneath the channel is shown in Figure 10. This shallow clay layer appears to exist (on the basis of analysis of well logs completed for this study) beneath nearly the entire reach between Madison Bridge and Moore Dam. This clay layer is the extensive division between the upper and lower

Actual Conditions Between Road 89 Bridge and Moore Dam



CONDITION 1, Early 1950's:

Recharge opportunity is at a maximum because storage is available in the gravel below creek channel even though clay layer restricts vertical movement. When low flow is restricted to thalweg only, infiltration and thus recharge opportunity is unchanged.



CONDITION 2, Present Time:

Creek bed has lowered to where thalweg is in contact with top of clay layer. Recharge opportunity is greatly reduced and occurs primarily through creek banks. When low flow is restricted to thalweg only, infiltration and thus recharge essentially ceases because of clay layer.

Figure 17. INFLUENCE OF STREAMBED LOWERING ON RECHARGE WHEN A CLAY LAYER IS PRESENT

gravel units as shown in Figure 10. In the early 1950s the streambed was approximately 12 to 18 ft above this clay layer, so that a greater volume of gravel existed below it, in which percolation could take place. However, the elevation of the streambed at the present time is such that only about 4 to 7 ft of gravel lie between the streambed and the top of this clay, as shown in Figure 10. A similar decrease in percolation opportunity occurs in the reach between Moore Dam and 1/2 mile upstream of Stevens Bridge, where the 50 ft thick gravel-rich alluvium is underlain by the Tehama Formation. Streambed lowering in this section also has had a similar effect of reducing percolation opportunity in the lower gravel unit (Figure 10), although the reduction is much less pronounced.

Future Consequences of Bed Lowering

A continuation of streambed lowering will have essentially the same effects as have occurred since 1950 (e.g., bridge undermining, groundwater storage loss, stream widening).

There is some time lag in the effects of bed lowering that have been observed to date. These effects are the result of the stream's attempts to smooth out the irregularies, caused by removal of aggregate in certain reaches, by moving bed material from the section upstream of the withdrawal area and by eroding the bed downstream. If aggregate extraction were to cease today, this process of smoothing the bed would continue for some time into the future (which cannot be predicted with the available information). Since this smoothing process can take place only during high flows, considerable changes may occur suddenly during some future very large flood. A case of point is the section of stream channel upstream of Madison Bridge. The thalweg elevation has lowered a progressively less amount for a distance of one mile upstream of Capay Bridge (where no bed lowering has been observed since 1913). This appears then to be the hinge point for bed lowering downstream.

If this point 1 mile up from Capay Bridge is only a temporary "hinge point," the bed could continue to lower from there upstream and downstream, such that Capay Bridge would begin to be undermined and Esparto Bridge would be further undermined. Capay Dam, which lies an additional 1.5 miles upstream may also be in danger from undermining at some future date. It is possible that the existence of Tehama Formation* material at shallow depth beneath the present stream channel may act to limit the potential for bed lowering in this upper reach of Cache Creek. If the hinge point and Capay Dam are founded on alluvium rather than Tehama Formation, and if Tehama is at a depth of 50 ft or more beneath the stream channel in this entire reach, then it is possible that the streambed may lower progressively with time, even if aggregate gravel extraction were terminated now. An assessment of this possibility would require an investigation well beyond the scope of this study.

The same latent effects may be present downstream of the aggregate operations between the Yolo stream gage and the settling basin. The Yolo stream gage information (Figure 5) clearly shows that the bed lowering has accelerated to approximately 0.74 ft per year since about 1964, and there is no indication that this rate is decreasing. However, this is not surprising since the aggregate extractions are proceeding at their post-1964 rate.

There is some evidence that suggests that the lag in the effects of bed lowering is not great in most reaches of the stream. This evidence comes from comparing the records of total volume represented by the bed lowering and the gravel extractions as recorded by the aggregate industry. These values are shown as the two plots in Figure 8. These plots are

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*The experience in this reach of the creek to date suggests that there may be Tehama Formation upstream from that point 1 mile upstream from Capay Bridge and that the Capay Dam may be founded on Tehama Formation. However, no evidence has been gathered during this study to substantiate that assumption.

essentially similar along most of their trend. It appears that the rate of loss of volume represented by bed lowering is approximately equal year-for-year to reported gravel extractions. This suggests that the time lag in bed lowering (at least at the Yolo gage) is nominal and that the lowering occurs in nearly direct response to upstream gravel extractions. Whether there is a similar response upstream from an extraction area is questionable (it could be resolved in the upper reach of Cache Creek by carefully gaging the bed at the Capay Bridge over several years). Since the extraction rate upstream of Stevens Bridge is nearly equal to extraction downstream of Stevens Bridge in the last portions of the 1970s, then a series of elevation surveys at the Capay Bridge would act as an early warning to streambed lowering there.

STREAM WIDENING

An evaluation of the widening of Cache Creek was carried out during this investigation. Aerial photographs taken in 1939 and 1972 were compared to determine where and how much change in the width of the stream had occurred during that 33 year span.

Amount of Widening

For this study, the line which represents the outer limit of the area of active erosion and deposition was chosen to define the change in creek area, mile-for-mile. This was done partly because only in certain reaches does the creek have definable banks that are without doubt the edge of the area of active erosion and deposition. Along most of the creek, this boundary is somewhat difficult to define and was identified in some places only on the basis of subtle evidence. The area of active erosion and deposition includes that portion of the creek's domain that is actively undergoing channelization during periods of high flow but not extreme flood stage. High flood areas were excluded because they exhibit subtle flood features, such as infilled channels and erosion scars, which are subdued by age, largely overgrown by vegetation, and have clearly not been flooded in the recent past. For both the 1939 and

1972 photos, this criterion was adhered to in order to have truly comparable stream domain boundaries. A separate overlay was constructed for each of the sets of photographs. These overlays were adjusted to match the scale of the USGS topographic maps of the area (1 in = 2000 ft) and corrected to eliminate photograph mosaic distortion. The differences between the two overlays were calculated in acres (by use of a planimeter).

The comparison of the photographs clearly showed that the creek has entrenched itself (i.e., eroded into a deeper, "trenchlike" channel) below the level visible in 1939. This has had the effect of creating terraces (primarily on the north bank) which are flooded only during high flood stage. These have been considered during our analysis as land *gained* since 1939. The creek has eroded primarily along the south bank and this has resulted in a loss of farm land. The sum of gains and losses of land by use of the above criteria shows a somewhat surprising result: in total, there has actually been a net gain of land along Cache Creek since 1939. That is, the area of active erosion and deposition was 73 acres smaller in 1972 than in 1939. What has occurred is that the creek has shifted southward slightly, eroding into its southern bank and creating terraces on its northern bank. The terrace formation amounts to gained land since it is now higher than the water level during all but the highest flood stages. However, the quality of the land gained differs considerably from that lost on the south bank, as discussed elsewhere. Note that, from this point forward, this report will use the term "meandering" rather than "widening," in light of the above concept that the stream has not really widened, per se.*

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*Note that the above conclusion that 73 acres have been gained between 1939 and 1972 is in sharp contrast with preliminary conclusions reached by the U.S. Army Corps of Engineers that 529 acres were lost from 1939 to 1970. The Corps study had a different objective and used a somewhat different criteria for "area within banks." Their 1970 calculation of area within banks is in fair agreement with our 1972 area of active erosion and deposition. However, in 1939, when the banks were difficult to delineate as compared to 1970, the Corps appears to have chosen a more restrictive definition of area within banks. It is the much smaller area of the 1939 "area within banks" calculation by the Corps that accounts for the wide difference in our two conclusions. In fact, the Corps' calculation of 529 acres lost agrees closely with our calculation of 588 acres lost, if the area of land gained due to creek entrenchment is ignored.

Location of Meandering

The gains and losses within the boundaries of the active erosion and depositional domain of the creek were identified and tabulated for each mile along the thalweg of Cache Creek. This information was derived by summarizing the boundaries of the active erosion and depositional area of the creek in 1939 and in 1972 and making a composite overlay of the difference depicted as either a gain or a loss in land during that period. These findings are summarized as follows.

Between Capay Bridge and a mile downstream, there has been a loss of 115 acres. From the latter point downstream to Esparto Bridge there has been a gain of 102 acres as a result of creek entrenchment and terrace development. From Esparto Bridge to Madison Bridge the south bank of the creek lost 84 acres and both the north and south banks gained 290 acres through terrace development in the section one mile upstream of Madison Bridge. From Madison Bridge to Moore Dam there has been a gain in land except for a very prominant loss of the south bank for a distance of 1-1/2 miles upstream from Moore Dam. The total gain in this reach equals 214 acres and the loss equals 112 acres. Downstream, between Moore Dam and Stevens Bridge, there has been a 110 acre loss of land primarily on the south side of the creek and a gain of 75 acres. Downstream, between Stevens Bridge and the constriction in the channel (located 1.5 miles upstream of Yolo) there has been 131 acres lost and 28 acres gained.

When the above values are summed algebraicly, the following gains or losses for the same reaches are calculated: Capay Bridge to Esparto Bridge, a net loss of 13 acres; Esparto Bridge to Madison Bridge, a net gain of 122 acres; Madison Bridge to Moore Dam, a net gain of 102 acres; Moore Dam to Stevens Bridge, a net gain of 35 acres; and Stevens Bridge to the constriction 1.5 miles upstream from Yolo, a net loss of 103 acres.

The lost land described above is due to the erosion of banks that were formerly above the flood plain. The gained land is land that was formerly in the 1939 creek domain that has been left behind as terraces above the main stream channel by the incision or entrenchment of the channel amounting to an average of 10 feet between Capay Bridge and Yolo.

Cause of Meandering

The most likely cause of meandering is streambed lowering. Under conditions of increased gradient caused locally by gravel extraction, the stream gains energy and thereby develops renewed erosive capacity. Thus, the stream will do work (i.e., expend energy) in response to its renewed erosive capacity and will apply this work in the easiest way possible. The energy may be absorbed as scour and lowering of the streambed, (if that is the easiest way), or it may attack the banks of the stream and widen its bed, (if that is easier). In either case it will adjust to the change in gradient. The gradient itself is controlled by local streambed lowering due to gravel extraction. The stream attempts to smooth out the irregularities developed by gravel extraction, and in so doing employs its erosive power along particular reaches of the stream.

In an attempt to establish why certain reaches of the creek meandered considerably while others did not, the banks of Cache Creek were examined. One of the most striking examples of stream meandering between 1939 and 1972 is the mile reach upstream of Stevens Bridge. The south bank at this location has lost approximately 73 acres during this time period. The banks of the creek in this reach were examined to determine the nature of the material exposed there. It was found that the material is a silty fine sandy loam and that the banks are approximately 18 to 20 feet high. No gravel or resistant

beds were observed in the stream banks. The soil has low dry strength and is devoid of any layering or material that could act as a deterent to stream erosion. The stream in this reach thus tends to meander rather than entrench itself.

A section that has shown a narrowing between 1939 and 1972 is the reach of Cache Creek between Madison Bridge and the I-505 Bridge. In the field, there is clear evidence that the creek has not widened here. The channel in this reach is only slightly wider than the width of the channel at Madison Bridge, and there is no evidence of attempts to prevent erosion (e.g., the use of automobile bodies and rubble dumped over the bank) which is common along those reaches which have widened. Examination of these banks showed that the upper portion was composed of silty fine sandy loam which is friable, easily eroded and similar to the bank material upstream of Stevens Bridge. However, the lower 5 to 8 feet of the banks is composed of silt-cemented gravel, which, in a dry state, appears to be quite resistent to attack by stream erosion. Thus, the lower section of the creek banks act as a deterent to the lateral meandering of the stream and prevent widening of the creek channel. The channel in this reach tends to entrench itself rather than meander.

Field evidence indicates that Cache Creek is adjusting to the extraction of aggregates in either of two ways. The stream either entrenches itself (in areas where the banks are resistant) or the stream meanders (where the banks are easily erodable). The creek, thus, utilizes its energy in whichever is the most efficient manner in its attempt to adjust to man-caused changes in its channel.

It is possible that a portion of the bank loss that has occurred since 1939 is a result of natural causes. The fact that most of the erosion has occurred on the south bank (rather than being distributed equally along both banks) suggests some natural control that is not

understood. Cache Creek has meandered beyond its present banks in the past, as shown by the ancient meander scars that are visible on aerial photographs. These meander scars are largely obscured by agricultural activity but are nonetheless evidence that the stream has meandered over a very large area in the recent prehistoric past. Furthermore, the limits of the full domain of the creek (as defined by the crest of the natural levees north and south of the present channel) is about 3/4 mile wide upstream of Stevens Bridge and approximately 1-1/4 mile wide downstream. The natural levees tend to keep the stream within this band at most stages of flow. Therefore, from a fluvial process standpoint it is not altogether surprising that the creek should change its course and erode its banks, as a natural phenonemon.

Effects of Meandering

In order to assess the impact on farmland along Cache Creek as a result of lost or gained land, two overlays were prepared showing the creekward extent of farming activities in 1939 and 1972. A comparison of these overlays defined the area of change. The total loss in agricultural area between 1939 and 1972 is equal to 765 acres. Of this total acreage, 142 acres were converted from agricultural production to use by the aggregate industry as processing plant area, 155 acres were taken out of production (lands tilled in 1939 that were present but not tilled in 1972), and 468 acres of tillable land were lost to erosion. During this same period, however, there was a significant gain of 331 acres of agricultural land (land tilled in 1972 but not tilled in 1939). This was the result of creekward development of agriculture due to: (1) tillage of land within the creek's domain which was previously available but was not tilled (50 acres), or (2) new tillable stream terraces made available by creek meandering and downcutting within the area of active erosion and deposition (281 acres).

The 142 acres converted to gravel plant area and the 155 acres taken out of production are not a consequence of streambed widening. Therefore, considering all of the acreage figures presented above, there has been an effective net loss of farmland of 188 acres.

The value of gained farmland is clearly not equal to the value of lost farmland. The land lost by erosion was in most cases prime farmland underlain by deep rich soil. In contrast, gained land is devoid of topsoil (including the upper silty capping layer below the topsoil) and only gravelly stream channel deposits remain. Nevertheless, locations are evident in comparing the 1939 and 1972 photographs where agriculture has taken a foothold on these gravelly deposits.

In summary, of the 765 acres lost to agriculture along Cache Creek, 468 acres of prime tillable land was lost due to erosion. This, coupled with the addition of 331 acres of newly tilled land within the creek's domain (most of which was made available by creek meandering) reduces the effective net loss of farmland to 188 acres.

Consequences of Stream Meandering

The material that was eroded by the stream meandering is likely to have been deposited, at least in part, in the stream channel. If the deposition did not take place in the channel upstream of Yolo then it likely was deposited in the Yolo settling basin. An estimate of the volume of this material is on the order of 16 million tons (assuming an average bank height of 15 feet and multiplying this by the 468 acres of agricultural land lost due to erosion). This eroded material (a silty fine sandy loam) would all be carried as suspended load in Cache Creek. Therefore, during flood flow conditions, the creek has the capability of carrying it out of the reach of Cache Creek covered in this study. If it were assumed that bank erosion took place at a constant rate between 1939 and 1972, then an average of 500,000

tons per year would be contributed as additional suspended load to Cache Creek. If all of this erosion were assumed to have taken place since 1950, when bed lowering first became more rapid, then the contribution to suspended load would amount to 700,000 tons per year.

These tonnage figures are very close to the estimates of suspended load that is deposited along Cache Creek between Capay and Yolo each year. The Corps of Engineers has calculated that 720,000 tons per year is deposited. Whitney Borland, (consultant to Woodward-Clyde during this study) estimated that 400,000 tons per year of suspended load less than 0.2 mm was deposited between Capay and Yolo.

If it were assumed that the entire suspended load eroded from the banks was deposited in the creek channel between Capay and Yolo, then the net effect would be deposition of twice the amount of fine grain material in the channel annually than would normally occur. At first glance, this increased sediment deposition would appear to reduce infiltration along the channel and thus affect recharge. Note, however, that the aggregate extraction operations remove all the bed material they collect in scrapers, including any fines that would have settled in the channel during the winter stream flow months. Gravel extraction occurs primarily during the dry season, therefore, the layer of sediment that would accumulate on the creek bed would be removed each year. Therefore, during this period of active aggregate extraction and consequent bed lowering, no significant effect on infiltration (and hence recharge) due to increased suspended load should have taken place.

A serious consequence of stream meandering is the potential for undermining the piers and/or abutments of the several bridges crossing Cache Creek. This effect is compounded by bed lowering which allows the creek to further undermine these structures. The bridge abutments

act as controls on the widening of the creek (both upstream and downstream of each bridge) by a fundamental fluvial process. Constrictions (i.e., narrow spots such as the bridge crossing) in a meandering stream channel have the effect of reducing the amplitude (i.e., maximum width) of the meander belt between constrictions, much as a series of fixed nodal points reduce the amplitude of a sine wave. Therefore, if the bridge abutments were to be washed out or new bridges were constructed with a wider span between abutments, Cache Creek might well adjust its flow regime to meander much more widely than it has in the recent past. Constrictions, either man-made or natural (e.g., the constriction above Yolo and the Dunnigan narrows), are deterrents to stream widening elsewhere along the creek.

Future Consequences of Continued Meandering

It cannot be stated with certainty whether the shifting and meandering of the stream that has taken place since 1939 will continue in the future, but the likelihood is that it will. The amount of lag in the cause-and-effect relationship is not known. Even in the sections of the creek channel in which entrenchment of the channel has taken place, there is the possibility that, given sufficient time, the lowered creek will gradually erode the terrace banks until the entrenched portion is as wide as the original creek. This could have the effect of eroding the area that has been gained to agriculture through entrenchment and terrace formation since 1939. It is Whitney Borland's opinion that there is good likelihood that the thalweg (which is clearly entrenched more deeply now than it was in the early 50's) may be the first stage of entrenchment and renewed widening at thalweg elevation. That is, the thalweg will widen out to form a new set of terraces and eventually erode those terraces to equal the present width of the stream channel. Since aggregate extraction currently continues, the effects due to

meandering that have been observed to date, are likely to continue as well. Normally the lag between the cause (streambed lowering)-and-effect (i.e., streambed meandering) is long, but if the lag were made up during a very large future flood, then profound changes may take place suddenly along the creek. Such changes, or even their likelihood, are not predictable without considerable further study which is well beyond the scope of this investigation.

Section VI

MANAGEMENT OPTIONS

Section VI

MANAGEMENT OPTIONS

Studies conducted on Cache Creek and discussions with the Aggregate Resources Advisory Committee indicate the need for a formalized public policy regarding the management of aggregate resources in Yolo County. This section discusses some of the basic considerations inherent in formulating an effective management policy, summarizes the major goals and objectives sought by private interests and public policy makers, presents a series of candidates which have been proposed to solve Cache Creek's problems; and describes the basis for selection. The section concludes with the consultant's recommendations on management policies and the course of action required for implementation and administration.

NEED FOR A MANAGEMENT POLICY

Numerous field observations of Cache Creek, a review of published and unpublished data, and discussions with people having first-hand experience with Cache Creek and conditions within Yolo County have led to the following conclusions:

- Significant portions of Cache Creek have undergone substantial physical changes over the past several decades (e.g., the streambed has lowered, the channel has widened and shifted, the surface/groundwater hydraulic regimes have changed).
- These changes have led to considerable localized property damage and environmental impacts (e.g., damage to bridges, loss of farmland, destruction of riparian habitat, lowering of water table).

- A continuation of the trends is expected to result in additional property damage and further environmental impacts.
- Some of the observed effects can be attributed to natural processes, but most have been induced by man's activities over the past few decades. Some of the effects are due to agricultural development and public works projects, but most of the significant adverse effects are a direct or indirect result of the aggregate extraction operations.
- The aggregate extraction operations also provide a variety of benefits to the area which tend to offset the adverse effects.

Therefore, that there is a need for a formal expression of public policy for future action. Because of the stakes involved, the Board of Supervisors have recognized that this policy should emerge from a careful consideration of both the desirable and adverse effects of continuing the aggregate extraction operations under a variety of different conditions and management policies.

OBJECTIVES

An "ideal" aggregate resources management policy would effectively accomplish a broad array of objectives. Because some of the objectives may not be compatible with one another, any real policy will necessarily involve considerable compromise. Nonetheless it is important to consider the full spectrum of objectives, since the candidate policies will be judged in terms of their ability to satisfy these objectives.

The Aggregate Resources Advisory Committee, working with the consultant, has identified the following as the objectives which should be pursued in formulating a management policy. No significance should be attached to the numerical order in which they have been presented.

Minimize Loss of Land. This reflects the desire to maintain property values and to minimize property damage and a variety of associated economic losses.

Minimize Flooding. This reflects the desire to maintain public safety and property values and to minimize property damage and a variety of associated economic losses.

Protect Groundwater Resources. This reflects the desire to maintain a reliable supply of quality groundwater and to minimize the need to extend wells and/or pump from greater depths. This reflects also the desire to avoid unnecessary expenditures of money or energy.

Protect Public Works and Irrigation Facilities. This reflects the desire to prevent damage to bridges, dams, and irrigation facilities by streambed lowering or bank erosion.

Maintain or Enhance the Aggregate Industry's Benefits to Yolo County's General Socioeconomic Well-Being. This reflects the desire to obtain the direct and indirect benefits of employment, earnings, and tax revenues resulting from the aggregate industry and its various associated industries (e.g., trucking, construction, equipment maintenance). This objective, as seen from the industry's point-of-view, would be to maintain an economically viable aggregate industry by minimizing labor and materials costs, minimizing the costs of processing and hauling the aggregate, and maintaining production volumes above the threshold level of economic viability.

Maintain or Enhance the Agricultural Industry's Benefits to Yolo County's General Socioeconomic Well-Being. This reflects the desire to obtain the direct and indirect benefits of employment, earnings, and tax revenues resulting from the agricultural industry and its various associated industries. This objective, as seen from the industry's point-of-view, would be to maintain an economically viable agricultural industry by minimizing labor a materials costs and maintaining productivity.

Maintain or Enhance Environmental Conditions. This encompasses such sub-objectives as minimizing adverse effects on water quality, air quality, and historical/archaeological/cultural resources as well as preserving or enhancing natural habitat, recreational opportunities, and aesthetic conditions (including control of noise, odors, dust, visual blight).

The following issues have also been expressed during the course of the study, but they are considered to be of lesser importance than the above objectives:

- Assure that aggregate materials will be available to Yolo County users at a reasonable cost over the next 50 years.
- Minimize the rate of filling the Corps of Engineers' Settling Basin (downstream from Yolo).
- Minimize the adverse effects of heavy trucking on roads, traffic safety, and traffic congestion.

Other factors which should be considered when the Committee and the Board of Supervisors ultimately decide upon a management policy are past statements of public policy. The following was expressed in the *County Master Plan* (1959):

> "Preservation of rich Yolo farm resources and the amenities of open space is, in the long run, the highest and best use of this land."

The *Open Space Element* at the General Plan (1972) reiterated this and went on to declare the following as objectives:

- Promote the agricultural use of land in the County.
- Conserve and renew the natural resources of the County.
- Enhance the watershed or groundwater recharge land in the County.
- Safeguard existing and encourage additional areas of wildlife habitat.
- Protect and preserve as many of the County's recreation resources as possible.
- Identify and support maintenance of areas of scenic value.

The *Conservation Element* of the General Plan (1973) declared the following as goals:

- Conserve the land forms of the County.
- Conserve the mineral resources of the County.
- Conserve the soils of the County.
- Provide sufficient quantity and quality water to meet the urban, agricultural, recreational and other needs of the County.
- Preserve and rehabilitate remaining habitat areas of the County to assure education experience opportunities, pleasant open space vistas and ecologically sound areas in the County.
- Preserve the historical heritage and vitality of the County.

TYPES OF MANAGEMENT POLICIES

Formulating an effective management program involves making decisions regarding: "what is to be done?" and "how will it be accomplished?" The "what" has been discussed, in terms of the stated objectives. Hence, the question, "what is to be done?" is answered by the statements of the objectives; e.g., "minimize loss of land", "minimize flooding". The "how will it be accomplished?" has two sets of answers, both of which must be worked out satisfactorily:

- The first has to do with the *administrative* aspects of the management program. This involves establishing who will have the authority/responsibility for the program and establishing the legal/political/economic basis for its implementation.
- The second has to do with the *technical* aspects of the management program. This involves establishing those physical things which will be prescribed to be done or not done (e.g., the operational requirements, constraints, remedial measures -- expressed in engineering terms).

The following discussion focuses first on the *administrative* aspects and narrows the range of choice by dismissing two extreme approaches which appear to be of limited viability. The discussion then focuses on the *technical* aspects.

Administrative Aspects

The following are alternative administrative approaches to resource management which have been considered during this study. It should be noted that some may not be acceptable (technically, politically, economically, and/or environmentally), but they have been listed here in the interest of completeness. No significance should be given to the order in which they are listed here.

No Formal County Control. Allow the aggregate extraction companies to regulate themselves. This would be a continuation of the County's laissez faire policies which have prevailed until recently.* It would constitute a County's waiving the responsibility and authority to establish formal policies regarding the industries' use of the natural resources and the resultant environmental, economic and socioeconomic effects.

Self-regulation. Allow the aggregate industry to regulate their own activities, but formally charge them with the responsibility for compensating affected parties (public and private) for specified types of adverse effects (e.g., loss of land, damage to structures, groundwater depletion). It would be the industries' responsibility to identify effective practices and implement and adhere to them. The industries' incentive for conducting effective programs would be their avoidance of costly compensation for damages. Under such a program, the County would set the goals but would not prescribe the means for accomplishing adequate levels of control.

County Control. The County would prescribe certain operational limits for the extraction industries to follow. The intent of these limits would be to minimize such adverse effects as property damage from stream bed lowering, channel widening, groundwater depletion. Under such a program, the responsibility for drafting and imposing truly effective controls would be the County's. The industry would be required to comply with the programs set forth by the County, but they would not be responsible for any damage which occurred.

Curtail Aggregate Extraction Operations. This approach would be taken if the decision maker were to interpret the adverse effects of the operations as being so severe as to outweigh the various benefits. Note that it could also come as a "de facto" result of overly restrictive management policies (either inadvertently or by conscious design).

Discussions with the Advisory Committee revealed that neither the first nor the fourth approach are acceptable. The first (i.e., no formal public control) would probably allow a continuation (and possible worsening) of the conditions which have led to the present public concern. The fourth (i.e., curtailing aggregate extraction operations) would resolve some of the physical and environmental problems, but would also result in a loss of the various direct and indirect benefits the

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*Note that the extraction industry is subject to considerable control by other regional, state, and federal jurisdictions.

industry provides. Hence, the Advisory Committee and the Board of Supervisors* are faced with the need to decide between the second or third approach, or working out some compromise which allows the responsibility to be shared in some acceptable manner.

Technical Aspects

The technical aspects of the management program have to do with the physical things which will be prescribed to be done (or not done) in order to meet the stated objectives. Thus, it has to do with determining the operational requirements, constraints, and remedial measures with which the aggregate industry will have to comply.

A variety of technical measures have been proposed from various sources during the course of this study. All would somehow accomplish part or all of one or more of the stated objectives, but the alternatives differ considerably from the standpoint of the degree to which the aggregate industry would be involved.

One approach would be to set regulations which the industry would adhere to during its routine operations and, by so doing, accomplish one or more of the objectives. An example would be to limit the excavation to a particular zone or a particular depth within the creek. This would partially satisfy some of the objectives and could be accomplished solely by the operator's actions. This and related approaches would consist of imposing only minor variations on the usual current practices.

Another approach would be to have the operators adopt techniques which are more pronounced departures from the current operations. For example, they could excavate large basins off-channel; grading and selling the excavated aggregates. The County or the Water District

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*This is clearly a political issue, in the broadest sense of that term. Woodward-Clyde has identified the issues to be resolved but cannot really make the decision as to how policies should be formulated and implemented.

could then use the completed basins for groundwater recharge in the short-term and for reservoirs and/or recreational lakes in the long-term. Such an approach would satisfy several objectives. However, it differs significantly from the former example in that the aggregate industry would be only one of several participants.

Yet a further departure would be for the County, the Water District, or some other agency to establish a system to recharge the aquifer directly (through pressure wells, unlined canals, etc.). This would achieve the objective of "protecting groundwater resources," but would not necessarily involve the aggregate industry at all. Therefore, it would not be an aggregate industry management plan, per se. Thus, the various alternatives discussed below vary considerably from the standpoint of the aggregate industry's involvement.

The alternatives also differ considerably from the standpoint of the objectives that they are intended to satisfy. The following discussion is structured such that it focuses first on those objectives which can be satisfied most directly by managing aggregate operations and then considers the effects on the objectives which are less directly influenced by changes in management practices. The objectives which are expected to respond most directly to changes in management practices are:

- minimize loss of land
- protect groundwater resources
- protect public works and irrigation facilities

The remaining four stated objectives (e.g., minimize flooding, maintain aggregate industry, maintain agriculture, protect the environment) would be influenced by various management plans but are not as directly affected as the former three. Hence, the approach here will be to focus first on alternatives which promise significant accomplishment on any or all of the former objectives and then consider the effects they would have on the latter objectives.

CANDIDATE TECHNICAL MEASURES

The following 21 measures have been identified as having potential for inclusion into an aggregate management policy. Note that some of these we would not recommend, but they have been proposed by others during this study and have been included here in the interest of completeness. The order in which they are listed is arbitrary and does not denote an order of importance.

- armor banks (e.g., riprap)
- plant erosion-resistant vegetation
- grade banks to a flatter slope
- build retards along banks
- build haul road levees
- build jetties out from banks
- flatten channel bottom, bank-to-bank
- dig numerous small pits in streambed
- periodically remove fines from bed surface
- build check dams
- build buried sills
- limit rate of extraction
- limit depth of extraction
- prohibit in-channel extraction
- build in-channel baffles
- armor bridge piers and/or abutments
- rebuild bridge piers
- build flow diversions upstream from bridge piers
- build off-channel recharge basins
- provide recharge wells
- build canals which promote infiltration

The following discussion is directed toward narrowing the focus of the study to those measures which appear to be most applicable.

The latter three measures may represent valid ways to accomplish the objective of protecting groundwater resources, but they are not really aggregate management plans, per se. Thus, discussion of them is deferred to Appendix C.

The following nine measures were dropped from further consideration, although they may well have application in certain reaches. This was done because they have been judged as having significantly lower potential for meeting the stated objectives over sizable portions of Cache Creek, given the prevailing economics. Their potential is discussed briefly below:

Armor banks. This would involve placing some erosion-resistant materials along the banks (e.g., rock or broken concrete riprap). This measure would be unquestionably effective if done properly, but its cost precludes its application in all but very localized areas. It may be useful for protecting bridge piers and/or abutments, but it would be uneconomical and impractical to use for the protection of many miles of Cache Creek's banks. Furthermore, the toe of the armored banks would still be quite vulnerable to erosion, should the streambed lowering be allowed to continue.

Plant erosion-resistant vegetation. While it is true that dense stands of vegetation once helped control erosion on Cache Creek, the concept of planting new vegetation now would have limited application. However, it may be an effective way to control erosion in the areas where little damage has occurred, so far. It might also have some application in other localized areas. But it would be ineffective and very costly to use this technique along most of Cache Creek unless it were done in conjunction with some considerably more substantial physical measure(s). Furthermore, the would be quite vulnerable, should the streambed lowering be allowed to continue.

Grade banks to a flatter slope. This concept may have some merit but is limited in its geographic applicability. It could be used to reduce erosion in areas where the banks are composed of gravel or hard clay and within the area where the aggregate operations are being conducted. However, it is not practical or effective to grade many miles of banks which are presently threatened by erosion. Given that the slope would have to be 3:1 or flatter, this would require either cutting into enormous acreages along the banks or would result in filling much of the creek. The resultant system would still be quite vulnerable to erosion, should the streambed lowering be allowed to continue.

Build haul road levees. This would involve building and maintaining raised berms parallel to the banks within the aggregate extraction areas. The berms would serve as both haul roads and in-channel levees. This practice (which has been conducted in the Solano Concrete operation) has the effects of defining the stream

course within the modified reach and protecting the natural banks there from erosion (although portions of the levees may be sacrificed during some floods events). However, the practice cannot be recommended for general applicability for several reasons. Along most of the stream, there is simply not enough room to accommodate in-channel levees and still pass floodwaters safely. Besides, the practice is very costly (especially if extended beyond areas which are being worked by the aggregate companies) and reduces the area exposed for groundwater infiltration. This practice also preempts the resource being sought (i.e. one cannot take either the material comprising the levee or the deposit below it), which may create greater pressure on accessible deposits. Furthermore, the resultant system would be highly vulnerable to erosion, should the streambed lowering be allowed to continue.

Flatten the channel bottom, bank-to-bank. This practice has been suggested as a way to minimize localized stream velocities with the intent of controling localized scour and increasing the retention time within a given reach (which could favor groundwater recharge). However, during high flows (when most of the erosion damage occurs), the stream would flow more freely within the modified reach and then cause greater erosion downstream (since the stream would have greater energy than if it had passed through a natural reach upstream). Furthermore, it is unlikely that a flat channel bottom could be maintained for more than a season or two. This practice may have some applicability in the wide basins where extraction is now being conducted, but even there the benefits are somewhat doubtful.

Dig numerous small pits in the streambed. This concept has been suggested as a way to assure that water from the stream is allowed good access to the permeable deposits which underlie the streambed. Further, it would provide somewhat longer retention time for water to infiltrate. The benefits would be largely offset by the pits' likelihood of trapping fine sediment and requiring routine reconstruction.

Periodically remove fines from streambed surface. This presently occurs where aggregates are being extracted, since the fines are taken along with the rest of the bed deposits. The benefit results from the fact that fines are not able to clog the pores of the deeper deposits (which would impair infiltration). This practice should probably be conducted as widely as practical, but the high cost of doing it independent of aggregate extraction operations limits its use to relatively small areas. In order for this practice to be extended further, a sizable market would have to be found for the fines so collected.

Prohibit in-channel extraction. This would make significant progress toward achieving most of the stated objectives, but would adversely affect the objective of "maintaining or enhancing the aggregate industry" to such an extent that it would probably not be considered viable, as a blanket approach (for political rather than technical reasons). There are areas where cessation of in-channel extraction may be necessary in the near future, however, if other measures are not taken to control streambed lowering. Presumably, the operations so affected would wish to pursue the alternative of extracting off-channel deposits.

Build flow diversions upstream from bridge piers. This would have the effect of directing the main flow of the stream away from the piers, thereby reducing the localized erosion and scour damage. This is not seen as a reliable solution to the bridge pier problems on Cache Creek, partly because the spacing of the piers is such that additional scour could result from increasing the velocities between piers. Also, Cache Creek is quite erratic in its flow regimes; the channel routinely moves from side-to-side (changing direction abruptly), and the flow depths and velocities vary over a considerable range. This would make it very difficult to prescribe effective means for diverting flow without inducing other problems.

The following nine measures appear to be most applicable to control problems on Cache Creek and meet the stated objectives:

- build retards along banks
- build jetties out from banks
- build check dams
- build burried sills
- limit the rate of extraction
- limit the depth of extraction
- build in-channel baffles
- armor bridge piers and/or abutments
- rebuild bridge piers

Figure 18 depicts the major mechanisms by which these measures would function toward satisfying the stated objectives. Most of the remaining discussion* is structured around this diagram. Note that the

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*This discussion is directed toward presenting alternatives at a conceptual level and examining their general applicability. It is not intended to be a comprehensive engineering analysis. Any decision to proceed with an alternative presented here must be accompanied by a thorough engineering analysis of where and how the measure should be applied.

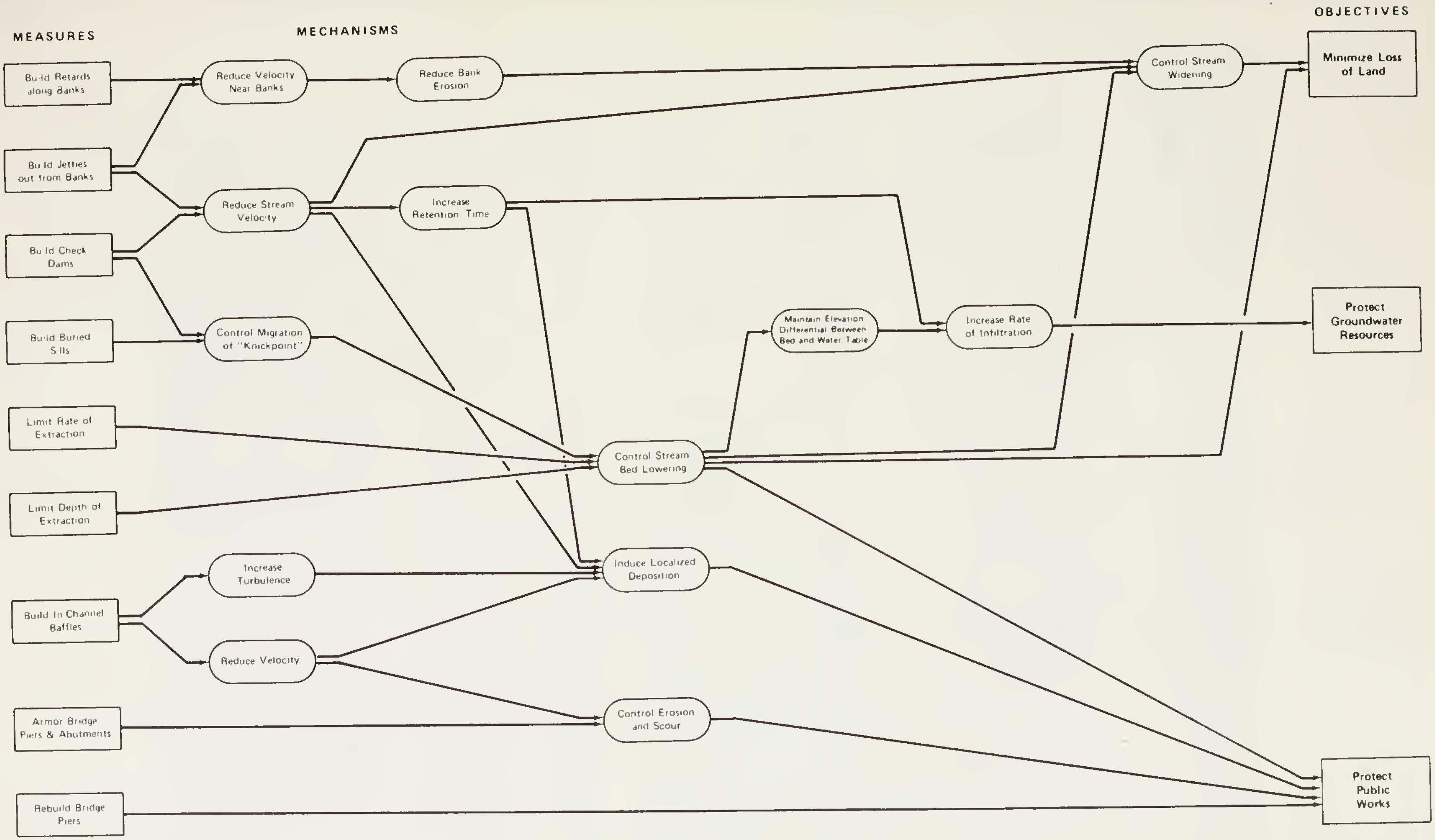
MEASURES
MECHANISMS
OBJECTIVES
Build Retards along Banks
Build Jetties out from Banks
Build Check Dams
Build Buried Sills
Limit Rate of Extraction
Limit Depth of Extraction
Build In Channel Baffles
Armor Bridge Piers & Abutments
Rebuild Bridge Piers
Reduce Velocity Near Banks
Reduce Stream Velocity
Control Migration of "Knickpoint"
Increase Turbulence
Reduce Velocity
Reduce Bank Erosion
Increase Retention Time
Control Stream Bed Lowering
Induce Localized Deposition
Control Erosion and Scour
Maintain Elevation Differential Between Bed and Water Table
Increase Rate of Infiltration
Control Stream Widening
Minimize Loss of Land
Protect Groundwater Resources
Protect Public Works

Figure 18. MECHANISMS BY WHICH TECHNICAL MEASURES FUNCTION TO ACHIEVE OBJECTIVES

order in which they are listed is arbitrary and does not denote an order of preference. Note also that effective control of problems may require the implementation of more than one measure and in more than one location along the stream.

Build retards along banks. The term "retard," as used here, refers to any of a variety of structures which would be built parallel to the bank, with the intention of diminishing the flow velocity along the face of the bank. Typical retard structures resemble fences and are usually made up of two or more rows running parallel to the bank. They generally have a wire or cable gridwork which is supported by uprights made of wood piling, steel pipe, or railroad track. Their open design allows water to pass through, but only at a reduced velocity.

If such retards were placed along the banks of Cache Creek in the areas most vulnerable to erosion, they could effectively control bank erosion, thereby controlling the loss of land and reducing the threat to public works structures. Control of stream widening could also help protect bridge abutments.

Because the retards would be parallel to the banks and would not extend out into the channel appreciably, their presence should not have much effect on the stream's behavior during flood stages. Therefore, they would neither assist nor detract from the objective of minimizing flooding. Nor would they have an effect on groundwater.

Their "environmental" impact would be mixed; they would surely detract from visual aesthetics, but they would help control the loss of existing bank habitat and might even provide niches within which riparian vegetation could establish.

This measure's effect on the agricultural and aggregate industries would be one of favoring their co-existance. It should be noted, however, that the effectiveness of any type of retard will be largely dependent upon the degree to which streambed lowering can be controlled.

Although costs are difficult to estimate at this stage of planning, it is likely that retards would cost on the order of \$150 to \$200 per running foot of bank (assuming cable and wire fence retards 6 to 8 ft high). These would be first costs to which routine annual maintenance costs would have to be added. The length of bank subject to active erosion is literally tens of thousands of feet, giving this measure a pricetag in the range of millions of dollars. Therefore, the use of retards will be limited to those areas where valuable cropland is in greatest jeopardy, and the costs are deemed justifiable.

Build jetties out from banks. Such structures could be of different sizes, shapes, and placement and could be built from a broad variety of materials, but all would consist of a linear obstruction, protruding obliquely out from the bank and extending part way across the creek channel. Given the pronounced range of flow conditions on Cache Creek, it is likely that a very rigid but pervious design would be most suitable (e.g., made up of cables and well-anchored pilings, spaced such that the flow would be impaired only enough to reduce the energy somewhat). The jetties would reduce stream velocities, locally, thereby helping to reduce the tendency to erode banks and public works. The jetties' effects on velocity and turbulence could induce some localized deposition of materials which would otherwise have been transported away. If built and located strategically, this could help protect bridge piers and could reduce some localized problems of bed lowering.

It is not clear whether a given installation would benefit or impair groundwater recharge. The jetty would not reduce flow velocities sufficiently to increase infiltration through lengthening the retention time in a reach. The deposition of sediments downstream of the jetty might help control streambed lowering (which might benefit groundwater in some reaches), but it could also result in clogging the bottom with fines (thereby reducing infiltration to the groundwater aquifer). Such issues would have to be studied on a case-by-case basis.

The jetties' effects on flooding potential are also difficult to predict at this stage of planning. They would not be expected to reduce the likelihood or severity of flooding but may not increase it either.

The environmental effects would probably be mixed, in that they would detract from visual aesthetics, would reduce adverse erosional effects on bed and banks, and could provide niches within which riparian vegetation could establish. The jetties would benefit both the agricultural and aggregate industries by favoring their co-existence.

The costs of jetties are difficult to estimate at this stage of planning because neither their form nor their spacing has been determined. However, it is likely that costs would be on the order of \$100 to \$150 per running foot of bank. This assumes 8 ft high cable and wire jetties running oblique to the banks with a length and spacing such that there are about 2 ft of jetty constructed for every foot of bank protected (e.g., 50 ft long jetties, 25 ft on centers; 100 ft long jetties, 50 ft on centers). If the jetties were made up of the large tetrahedral "jacks" (often used for shore protection), the costs might be lower; possibly on the order of \$40 to \$60 per running foot of bank (assuming similar spacing of jetties). Routine maintenance costs would have to be added to these first costs.

Since the length of bank subject to erosion is literally tens of thousands of feet, this measure could cost on the order of a million or more dollars, if widely employed. Therefore, it is likely that jetties will be considered most applicable where valuable cropland is in jeopardy.

It should be noted, however, that the U.S. Army Corps of Engineers (Sacramento District) has been considering the possiibility of using large arrays of jetties for the primary purpose of inducing sediment deposition in Cache Creek (to extend the life of the Settling Basin near Yolo). If the County (and/or the aggregate industry) can work out a program that is consistent with the Corps' project goals, it is conceivable that the Corps may assist in building jetties which would benefit Cache Creek in several ways.

Build check dams. The concept here would be to build a series of low dams across Cache Creek such that the water would work its way downstream in a stair-step fashion. The purpose of this is severalfold. If built* with long, flat crests, the check dams would cause the stream to flow over a greater surface area, thereby reducing velocities, expending more energy, and increasing retention time (which would favor infiltration). Additional energy would be expended as the water dropped over the check dams. Since the energy of the flowing water is what gives rise to its erosional potential, use of such dams could reduce the loss of land through bank erosion and could reduce bed scour. Also, the check dams would serve as positive controls on the upstream migration of the knickpoints. Control of the knickpoints' upstream migration is essential to making any significant achievement on any of the stated objectives. To the extent that knickpoints are allowed to migrate upstream and induce bed lowering, all of the objectives will be threatened, and all of the other remedial measures will be limited.

It is recognized that the check dams would quickly fill up with deposited sediments. Rather than being a detriment (which it is with dams intended to provide water storage) this deposition could be a beneficial feature of the design. If the dams were built and located strategically, deposition of sediments could be used to help protect bridge piers from decomposition, corrosion, and partly from erosion (i.e., if the dam were just downstream from the piers).

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*Note that the design of such facilities is well beyond the scope of this study. If this or other engineered facilities are judged to be desirable for use on Cache Creek, the detailed engineering studies will be required to select the proper locations and design the facilities.

Furthermore, the dam would trap materials which could be subsequently removed. Conversely, the deposition of fine sediments would reduce the porosity of the bed, thereby impairing infiltration over the reach affected. At this stage of planning, it is impossible to know the net effects of these conflicting phenomena.

The cost of check dams depends heavily upon their height, length, and general design; none of which can be prescribed at this stage of planning. However, if the dams were built from concrete and were, say 6 to 8 ft high, they would cost on the order of \$60,000 to \$80,000 per 100 ft of crest length (this assumes an actual dam height of about 15 to 18 ft, most of which is buried).

The places where the check dams would be most effective are as follows, listed in order of decreasing importance:

- in the narrows upstream from the bridge on the Madison-Dunnigan Highway (i.e., at the upper extent of the upper major excavation basin)
- just downstream of the Stevens Bridge
- in the vicinity of the I-505 crossing*
- just downstream of the Madison Bridge on Road 89

In all of these areas, the creek is several hundred feet wide, meaning that the cost of each dam would be on the order of hundreds of thousands of dollars. However, based upon the relationship between bed lowering and the many observed impacts, some kind of positive, physical control on bed lowering is needed.

Build buried sills. This measure is quite similar in many respects to that of building check dams. The sills would be like small dams, except they would be buried in the steambed such that their crests are level with the streambed. Their principal function would be to provide a firm control on the upstream migration of the knickpoints induced by downstream excavation. By controlling the streambed lowering, most of the stated objectives would be benefitted. There would be a reduction in loss of land, the bridges and groundwater resource would be in less jeopardy, riparian vegetation would be able to establish more easily, and the agricultural and aggregate industries would be more able to coexist. The likelihood and potential severity of flooding would probably be unchanged.

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*The County and/or the aggregate industry may wish to contact Cal Trans (Sacramento office) to see if they can cooperate in some type of check dam which could protect the bridges and provide other benefits as well.

Such sills could be somewhat less costly than check dams, amounting to perhaps $10,000 to $20,000 per 100 ft of crest length. They could be built in a variety of ways, from a variety of materials (e.g., concrete, sheetpile). The sills should be placed as cited above for check dams. Since the sill lengths in these locations would be several hundred feet, their costs would be in the range of tens of thousands of dollars. If the sills were incorporated into the plans to protect or restore existing bridges, some cost sharing may be feasible.

Limit the rate of extraction. By reducing the rate at which aggregates are extracted from Cache Creek, some of the problems would be resolved, and some would be postponed somewhat. If the extraction rate were to be reduced to perhaps 70% to 80% of its present rate, virtually no benefits would result. If, on the other hand, the rate were reduced to only 20% to 30% of the present rate, there could be significant achievement on several of the stated objectives, but the objective of "maintaining or enhancing the aggregate industry" would be largely forfeited. The reason why reducing the extraction rate would have only a moderate effect on resolving the problem is twofold:

- the present extraction rate is approximately ten times the natural replenishment rate (so a reduction of 90% would be required, just to achieve steady-state conditions).
- most of the pronounced problems are caused by streambed lowering (some partially, some primarily), the effects of which take many years to work their way upstream. Hence, many of the problems experienced now are a result of excavations made years ago. Also, limiting excavation now would not resolve the problems in the near future (unless other, more direct measures were taken to control bed lowering).

It should be noted that a reduction of overall extraction rate could not be done very uniformly, since a given aggregate operator cannot afford to cut the scale of his operation very far and still be financially viable. Thus a reduction to 70% or 80% of the present rate would probably result in one or two companies going out of business (or moving off-channel) rather than all companies operating at a reduced rate.

It should also be noted that reducing the extraction rate too far would have some unfavorable effects. For example, there could be a gradual accumulation of sediments in some reaches which are now kept relative clear (as a direct or indirect result of aggregate extraction). This could eventually lead to reduced infiltration and possibly more severe flooding.

Another aspect of the concept of limiting the rate of extraction has to do with prescribing an upper limit on the amount of aggregate which may be extracted prior to the year 2025 (or any other year and/or intermediate years). This would have the effect of establishing some degree of public control over resource depletion without placing undue constraints on today's industrial enterprises.

Limit the depth of extraction. This measure is so important that it can hardly be considered optional, since there are certain areas along the creek where it could be highly detrimental to allow the bed to lower much below its present elevation. Such an area would be the reach between Esparto Bridge and Stevens Bridge. This may have serious implications regarding the aggregate companies which operate there; i.e., Syar Industries, Cache Creek Aggregates, and Solano Concrete Co. These companies currently account for approximately half the tonnage extracted on Cache Creek (and approximately half of the benefits as well). Nonetheless, the findings of this study indicate that it is very important that excavation limits be set for this reach and the areas just downstream.

The limits should probably take the form of performance specification stating that aggregate operations cannot be conducted in the prescribed area unless the mean streambed elevation is higher than X ft above mean sea level and/or the thalweg elevation is higher than Y ft above mean sea level. Note that, the limits could be set deeper in some cases if some form of positive physical control (e.g., check dams, buried sills) were established to prevent upstream bed lowering. Downstream of Stevens Bridge, it is possible that relatively deep excavation could be accommodated, if it were conducted carefully, and if provisions could be made to control the migration of the knickpoint.

Build in-channel baffles. This concept is similar to that of building jetties, in that both would be measures to locally reduce velocities and induce turbulence. The in-channel baffles could be placed upstream from the bridge piers. These could be capable of reducing erosion and scour around bridge piers and abutments and may be able to induce some local deposition of coarser materials (which would further assist in protection). The design of such baffles would have to be carefully worked out by engineers with experience in erosion control. This measure probably would have only a moderate likelihood of achieving the objective of protecting public works and would not contribute to the other stated objectives in a significant way. The cost of building such baffles cannot be estimated at this stage of planning.

Armor bridge piers and abutments. This would involve placing any of numerous types of physical armoring around the exposed faces of piers and abutments to control erosion and scour. Candidate systems might include rock or broken concrete rip-rap, rock-filled wire mesh gabions, or rock-filled timber or steel cribs. Since the effects would be very localized, there would be no appreciable effect on the other stated objectives. Note that such a measure could still be quite vulnerable to streambed lowering.

The cost of armoring bridge piers with rip-rap might amount to $20,000 to $30,000 per bridge (depending upon how high the rip-rap extended and what materials were used). If rock-filled gabions or cribs were used, the costs would be higher still.

Rebuild bridge piers. This would involve reconstructing the footings of the existing bridges, an approach which has already been done several times on some of the bridges. Most of the past rennovations have been negated by severe streambed lowering and local scour. Thus, any new project should carefully consider the potential for further lowering. The effects of this alternative would be localized and would not have any appreciable effect on any of the other stated objectives. No costs have been estimated for the reconstruction of bridges.

SELECTION OF A POLICY

Any actual resource management plan will necessarily involve many compromises, since not all of the objectives are compatible within the existing legal/political/economic/environmental framework. Nor are any of the control measures of any practical plan fully effective. Nonetheless, the decision-maker cannot have "the best of all worlds," so it is necessary to evaluate the tradeoffs involved in any policy considered. The selected policy will be one which represents the decision-maker's opinion as to what constitutes the most acceptable balance among the various beneficial and adverse effects upon the stream, the natural environment, the natural resources base, and the prevailing legal/political/economic realities which exist in this part of Yolo County. That is, it may be necessary to forego some policy option which would be very desirable on the one hand, if it is not economically feasible, legally defensible, politically viable, and environmentally acceptable.

It should be recognized that one of the most difficult things facing the decision-maker is the uncertainty surrounding the cause-and-effect relationships affecting the conditions on Cache Creek. There is uncertainty as to how much of the observed damage to date has been caused by the aggregate extraction operations, as opposed to other contributory factors (natural phenomena and other man-induced effects). There is uncertainty as to what addtional adverse effects would occur, even if extraction were curtailed altogether. In fact, there is considerable uncertainty as to what will be the ultimate consequences of implementing any management policy (since there are limitations on the technical understanding of cause-and-effect relationships). Moreover, there is uncertainty as to what external social and economic changes will occur over time and what effect these may have on the validity of any policy formulated now.

Nonetheless, the decision-maker does not have the option of waiving his responsibility. Some public policy will emerge (to take no action would, of course, be equivalent to having selected a management policy).

A primary goal of this study has been to inform the Advisory Committee, the Board of Supervisors, and the public in general about the problems (past, present, and projected) and the implications of chosing among various alternative "solutions". As consultants, we have developed a view as to what course we would favor, however, the decision really falls upon the people of Yolo County, through their elected and appointed representatives.

CONSULTANT'S RECOMMENDATIONS

As a result of the field observations and data analyses conducted during this study, and the many discussions we have had with the Advisory Committee and with local residents, the study team has developed an opinion as to what actions the County should take. Given our present state of technical knowledge of the problems and our impression of the public attitudes regarding the prevailing legal/political/economic/environmental conditions, we would suggest that the Advisory Committee recommend that the Board of Supervisors consider the following proposals (the order in which they are listed is arbitrary and does not denote the order of importance):

1. Establish a requirement that all aggregate companies operate under conditional use permits, where mining and restoration plans would be required as part of the permit application.
2. Establish limits on the streambed and thalweg elevations for specified reaches of Cache Creek, with elevations specified for different points in time (e.g., 1980, 1985, 1990).
3. Construct provision for positively controlling knickpoint migration in certain areas (e.g., by the use of check dams, sills).
4. Allow the aggregate companies most affected by the above constraints on streambed lowering to work out arrangements to acquire suitable land along the banks to mine.* This would require a careful consideration of the concept of "the best use of the land", land values, land ownership, land use controls, and the Williamson Act provisions. It would also involve hydraulic considerations of where such extraction could be practiced without adversely affecting stream flow conditions.
5. Allow the aggregate companies most affected by the above constraints on streambed lowering to work out arrangements to acquire suitable off-channel areas to work as open-pit mines.* The most practical approach

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*This approach could reduce the likelihood of accelerated streambed lowering and would establish a more equitable relationship between the extraction industry and the parties who own the aggregate-bearing land.

may be to construct some type of cooperative venture involving one or more aggregate company, the County, the Conservation District(s), and/or the Water District. To do this would require a careful consideration of such factors as land values, land ownership, land-use controls, the concept of "the best use of the land," Williamson Act and other legal constraints, water rights, water costs, and the concept of "the best use of water as a diminishing resource."

6. Build retards or jetties to protect areas where high quality farmland is in greatest jeopardy; drawing upon as wide a financial base as possible (i.e., involving participation by such groups as land owners, conservation districts, aggregate companies, the County, the Corps of Engineers).

7. Discourage those extraction practices which result in promoting flow through the modified reaches (e.g., by making them straighter, steeper, and/or smoother), since this allows the water to move into downstream reaches with more energy and hence more erosive capacity (it also diminishes retention time and recharge).

8. Establish a regular periodic review of conditions along Cache Creek, focusing on streambed lowering, condition of bridges, meandering, groundwater conditions, and aggregate production volumes. This should take the form of a long-term "monitoring" program (probably best managed through the County Public Works or Planning Department) which would involve:

    - surveying mean streambed and thalweg elevations each spring at several selected locations
    - inspecting the bridges each year
    - sending out questionnaires to landowners along the creek to determine the extent of erosion (or deposition) which has occurred
    - compiling information on groundwater table elevations as measured at several selected wells
    - sending out questionnaires to the various aggregate companies to collect annual summary information on production volumes, employment, taxes, and any deviations from their mining plan (as submitted when applying for their use permits).

At the request of the Committee, Woodward-Clyde Consultants have compiled the following list of studies that would shed light on aspects of the subjects discussed herein:

1. Conduct a study to decide upon a public policy concerning the concept of "what constitutes the best use of particular land areas along Cache Creek?" This would be similar to the type of effort which goes into the establishment of zoning or a general plan land use patterns. The benefit of this effort would be that it would help guide subsequent decisions regarding off-channel extraction or intentional bank extraction.

2. Initiate an engineering study of the bridges on Cache Creek (e.g., Stevens, Madison-Dunnigan, Esparto) to determine their present safety and their projected safety over the next five to ten years (given that no further bed lowering or scour occurs, but that no remedial measures are taken to repair the bridges). The study would then recommend what should be done with the bridges (e.g., repair and protect by armoring, replace, close). A special part of the study would investigate the concept of building a sill-like structure into the bridges to simultaneously protect their footings and control streambed lowering.

3. Conduct engineering studies to determine the best location for the candidate control measures; including a consideration of effectiveness and costs.

4. Conduct a study to determine the streambed elevations which futute control measures should attempt to maintain. Note that the appropriate elevation is not an absolute thing, for a given reach of stream. The elevation selected will represent some compromise position which reflects trade-offs of the following sort of factors: economics (industrial economics and public finance), environmental and aesthetic considerations, land and resource management considerations, legal/political considerations.

5. It is recommended that the County continue to pursue means of obtaining information on sediment transport in Cache Creek. If the costs of a continuing USGS monitoring program cannot be justified, perhaps some other means of collecting similar information can be worked out (e.g., using Water District staff, County staff, U.C. Davis students, local volunteers, or perhaps aggregate industry personnel).

APPENDIX A

APPENDIX A

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APPENDIX B

APPENDIX B

GLOSSARY

Fluvial - pertaining to streams or produced by the action of flowing water.

Gradient - the rate of drop of elevation as the stream descends along its course.

Habitat - the place where a plant or an animal species would naturally live.

Knickpoint - an interruption or sudden break of slope in the longitudinal profile of a stream.

Meander - the turning or winding of a stream.

Niche - the sum of the physical and biotic life-controlling factors (e.g., climate, predators, food, water sources) that are necessary for the existence of an organism in a given habitat.

Passerine - pertaining to song birds.

Retard - a bank protection structure intended to locally reduce stream flow velocities.

Riparian - pertaining to the banks of a stream

Riprap - rock, broken concrete, or other hard, dense materials used as bank or shore protection.

Salmonid - a fish, like or related to the *Salmonidae* (e.g., trout, steelhead, salmon).

Thalweg - the line or thread of a stream that constitutes the lowest or deepest part of the stream channel.

Transmissivity - the rate of flow of groundwater through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity is equal to the permeability times the saturated thickness of the aquifer.

APPENDIX C

APPENDIX C

HYDROLOGY

GROUNDWATER RECHARGE

Surface water recharge to groundwater in the Cache Creek alluvial fan occurs through percolation from several sources. These sources are (in order of decreasing significance): deep penetration of rainfall, percolation from streams, deep percolation of excess applied surface water, and leakage from unlined irrigation canals. Since groundwater in the Cache Creek alluvial fan is for the most part unconfined to semi-confined, recharge can occur nearly anywhere.

The importance of deep penetration of precipitation as the major source of recharge is evidence of the reaction of the water levels in wells far removed from either percolating streams or unlined canals. These water levels rise very rapidly after heavy precipitation. Precipitation must, of course, first satisfy the requirements of depleted soil moisture and consumptive use, before deep percolation can take place.

Deep percolation from excess applied surface water is important as a source of recharge to the Cache Creek groundwater basin because of the magnitude of surface application and the thorough coverage of the area by surface water supplies. The existence of a high water table in the fall season around areas of surface application is regarded as evidence for this conclusion. However, the geology and pattern of groundwater recharge and extraction tend to confuse the effect of applied surface water on groundwater levels. Similarly, leakage from irrigation canals contributes substantial recharge because the extensive coverage of the area by the canal system includes many miles of unlined

ditches. The California Department of Water Resources (DWR, 1961) calculated that losses in unlined canals account for about 23 percent of the total water diverted by the Clear Lake Water Company.

The relative importance of each of the sources of recharge is shown by the following estimates of annual groundwater recharge during the six year period 1953-59 (DWR, 1961):

- precipitation — 66,000 acre ft
- stream percolation — 26,500*
- canal losses — 24,000 acre ft
- deep percolation of excess applied surface water — 16,900 acre ft

Thus, stream percolation in Cache Creek amounts to only 19 percent of the total recharge to the groundwater basin.

The high water table in the reach between approximately Esparto Bridge and Moore Dam causes groundwater to move into the stream channel to support surface flow. The creek thus gains flow along this reach. DWR (1961) calculated during their 6 year study (1953-59) that the average contribution to stream flow from this source was approximately 1,000 acre ft per year. The creek probably loses the gained flow during infiltration along the section of creek channel between Moore Dam and the constriction 1.5 miles upstream of the town of Yolo. This loss however, would only occur during low flow when that small quantity of total flow is a significant proportion of stream flow at that moment. In effect, such recharge is a transfer of groundwater from the upper basin to the lower basin via surface flow in Cache Creek.

Flow loses were defined for two distinct reaches of creek channel: important amounts from Moore Dam downstream to about 1.5 miles

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*25,500 acre ft of this value are percolation from Cache Creek.

upstream of Yolo and lesser amounts from below Capay Dam downstream to Madison Bridge. Between Madison Bridge and Moore Dam, Cache Creek has historically gained water. Rising water in this reach of the stream is derived from a high water table in the Hungry Hollow area to the north. From 1.5 miles upstream of Yolo to the Cache Creek settling basin, the creek apparently neither gains nor loses significant amounts of water.

The above assessment of gaining and losing reaches was refined during the period 1952 to 1957 by the U.S. Geological Survey (Richardson and Rantz, 1961). This investigation consisted of measuring the flow in the creek at eight temporary stream gaging stations during the dry summer months to determine whether the reach between stations either gained or lost flow. They determined that the reach between Esparto Bridge and Moore Dam generally gained flow during the dry season (i.e., water flow increased along the creek between these two points). The reach between Capay Bridge and Esparto Bridge always lost flow. The reach between Esparto Bridge and Madison Bridge always gained flow at low water stage and lost flow at flood (i.e., through bank storage). The reach between Madison Bridge and Moore Dam gained a high water table position and tended to lose flow during low water table position. The section between Moore Dam and Stevens Bridge always lost flow. The section between Stevens Bridge and Yolo stream gage always lost flow.

Observations during the current study along Cache Creek suggest that standing water in the creek along specific reaches is a phenomenon independent of whether the years are wet or dry. In other words, although this year (1976) has been unusually dry, with the water table considerably below the long-term average, there has been flow in many reaches of creek where none might be expected. Furthermore, flow appears then disappears again further downstream, showing that the source is clearly not a surface source. The explanation for most of these occurrences of standing (and often flowing) water in the creek channel

is that it is "perched" groundwater (i.e., groundwater that is maintained at a high level by a clay layer that is sufficiently extensive and at sufficiently shallow depth to prevent the groundwater above from draining downward to the regional water table). The clay layer that divides the upper and lower gravel units (shown in cross-section in Figures 9 and 10) in the reach between Madison Bridge and Moore Dam could cause such an effect. This same clay layer may be responsible for the reduced recharge along Cache Creek suggested by Scott, et al, (1975).

The gaining reach between Esparto Bridge and Madison Bridge as identified by Richardson and Rantz (1961) may be the result of this same thick clay layer that divides the upper and lower gravel units. The clay layer intersects the 1974 thalweg just upstream of Madison Bridge (Figure 10). This point of intersection acts like the lip of a cup and may retard the eastward movement of groundwater in the upper gravel upstream from this point. Groundwater may therefore be ponded in the upper gravel unit upstream of Madison Bridge and be forced by the clay layer to flow into the creek channel in order to escape. During the current study, water was observed to be standing in the creek channel upstream of Madison Bridge only to disappear within a few feet downstream and the channel remained dry to the I-505 Bridge. The standing water upstream of Madison Bridge may have been a function of the above described subsurface condition.

ARTIFICIAL RECHARGE

Means for increasing the recharge opportunity during periods of high flow in Cache Creek are to increase the exposed surface area of coverage and/or to increase retention time within the area of infiltration. The use of abandoned or active gravel pits would accomplish both of these basic requirements. The location for recharge pits is critical, as the previous discussion illustrates. Recharge from gravel pits located in the reach downstream from approximately Stevens Bridge would be most favorable because the water table is consistently below the channel and because there are few clay layers to impede percolation. The reach from Capay Bridge to Esparto Bridge has also historically been an important area for recharge because the water table is consistently below the channel and no extensive clay layers are present in the near surface. On the other hand, the reach between approximately Esparto Bridge and Moore Dam has historically been a poor recharge area, either because of an extensive clay layer beneath the stream channel or because of a historically high water table. This reach is not recommended for artificial recharge.

Recharge could be accomplished by flooding off-channel basins in locations where infiltration from the near surface would be possible. Water could be ushered to the basins through canals during the winter months when these canals are not used for surface irrigation. This would have the effect of both increasing the infiltrtion from the canals (which, being unlined, allow considerable leakage) and from the artificial basins.

Recharge from deep percolation of leakage from unlined canals represents 18 percent of the total annual net groundwater recharge (DWR, 1971). Normally these canals are active only during the irrigation season, since no diversion of water takes place during high

flows from Capay Dam. If the canal network were kept full during the high flow winter months, then infiltration of the recharge area and retention time would be increased to maximize infiltration in the available system.

Recharge through unlined canals has several advantages over recharge in Cache Creek itself:

- The canal system distributes water over a much larger area than the stream channel itself
- New canals could be constructed to strategically place water in a specific location where extreme groundwater lowering is taking place
- Recharge from unlined canals could occur during all times of the year, even when the water table is so high that recharge in Cache Creek no longer takes place (during the spring and winter wet season).*

There is a certain disadvantage to canals because of the surface silt and clay layer that seems to overlay the entire groundwater basin. Since the canals are not incised very far beneath ground surface they are likely underlain along most of their length by the capping soil. The lower permeability of this layer as compared to the gravelly channel deposits in Cache Creek could make it such that the canals are somewhat less efficient as recharge sources than the channel of Cache Creek itself on a mile-for-mile basis. However, the larger number of miles of canals could well make up for this difference.

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*The reason for this latter feature is that the canals are not incised very far below the ground surface. An example of this is shown by Adams Canal on the north side of Cache Creek. At one point the canal bottom elevation is 140 ft while opposite the canal on Cache Creek the present creek bed elevation is only 95 ft. This is a 45 ft difference in elevation which provides 45 feet of additional head for recharge (under saturated conditions) from the canal as compared with the stream channel. In fact, it is along this section of Cache Creek that recharge does not take place during periods of high water level.

The use of pressurized, drilled wells as a means of promoting artificial recharge of aquifers cannot be recommended for this area; partly because of the high cost of building and operating the wells and distribution system (i.e., the wells are costly and will tend to become clogged unless the water is pretreated) and the ineffective use of energy involved.

APPENDIX D

AGGREGATE TESTING

APPENDIX

Standard Laboratory Acceptance Tests

To be suitable, an aggregate has many requirements that are difficult to meet if only unprocessed material from natural deposits is used. Suitable material is composed of clean, uncoated, properly shaped particles which are sound and durable. Soundness and durability are used to denote the ability of aggregates to retain a uniform physical and chemical state over a long period of time so as not to cause disruption of the concrete when exposed to weathering and other destructive processes. To have these attributes, individual particles must be tough and firm, possessing the strength to resist stresses and chemical and physical changes such as swelling, cracking, softening and leaching. The aggregate should not be contaminated by much clayey material, silt, mica, organic matter, chemical salts, or surface coatings.

In addition to containing particles which are individually sound and durable, the deposit should contain an over-all assemblage of particles which can be processed to obtain the proper size grading. The grading of concrete aggregate has very pronounced influence on the workability of the concrete mix and the proportion of cement and water needed to produce high-quality concrete.

The geological and engineering aspects of an investigation of alluvial deposits to evaluate their suitability for aggregate has been covered in numerous articles, some of which are given in the list of references. For a brief review of the subject the reader is referred to the article *Sand and Gravel for Concrete Aggregate*, by H. B. Goldman, in the January 1956 issue of the *California Journal of Mines and Geology*.

Laboratory testing is a means of scientifically evaluating the suitability of aggregate material. In an attempt to forecast the behavior of the aggregate in concrete, numerous tests have been devised, many of which are complicated and require expensive equipment and trained technicians. Several of these tests have been used for many years and are familiar to those in concrete construction work. A strong effort is being made to standardize testing procedures throughout the nation and many laboratories use, with little or no modifications, test methods as set forth in detail by the American Society for Testing Materials. The principal tests performed on aggregates are for toughness and abrasion resistance, soundness, organic content, grading, specific gravity, absorption, and alkali-aggregate reactivity. Petrographic examination supplements the laboratory tests.

Toughness and resistance to abrasion are determined by abrasion tests, such as the Los Angeles Rattler and wet shot tests.

Los Angeles Rattler Method. The Los Angeles Rattler method is used to determine the resistance of mineral aggregate to combined impact and abrasion in a rotating cylinder containing metallic spheres. The procedure consists [illegible] placing a graded and weighed sample in a metal cylinder 28 inches in diameter and 20 inches in height with 6 to 12 iron or steel spheres approximately 1⅞ inches in diameter, each weighing about 1 pound. The machine is rotated about a horizontal axis at a speed of 30 to 33 rpm. for 100, 500, or 1,000 revolutions, after which the sample is removed, resieved, and reweighed. The difference between the original and the final weight of the test sample is expressed as a percentage of the original weight and reported as the percentage of wear.

Wet Shot Method. The wet shot test is conducted in a manner similar to the Los Angeles Rattler test, except that water is present in the cylinder.

Soundness of aggregates is determined by two methods: the quick sodium sulfate (or magnesium sulfate) test, or the slower freeze-thaw test.

Sodium Sulfate (or Magnesium Sulfate) Soundness Test. The soundness of aggregates is determined by a quick test-method which measures the resistance of aggregates to disintegration by the force of crystallization of salts absorbed from saturated solutions of sodium or magnesium sulfate. The procedure involves sieving and weighing the samples, immersing desired size-gradings in prepared hot solutions of these salts for 16 to 18 hours, removing and drying, and then repeating the entire cycle. After the final cycle, the samples are washed, dried, resieved and reweighed. The weighted average percent loss is then calculated from the percentage of loss for each fraction. The fraction larger than ¾-inch is examined visually to detect any disintegration, splitting, crumbling, cracking, flaking, etc., caused by crystal growth in the fractures, pores, and capillaries.

Freeze-Thaw Test. The freeze-thaw method consists of mixing the aggregate sample with a standard mixture of cement, entrained air, and water to form test beams. These beams are cured and then subjected to cycles of freezing at 0° C and thawing to 40° C. The change in the dynamic modulus of elasticity is measured periodically by sonic equipment (electronically). Durability is judged by the percent change in the modulus of elasticity with continued cycles of freeze-thaw. This method has the disadvantage of being much slower that the sodium sulfate (or magnesium sulfate) test.

Organic Content. The organic impurity in the finer fractions of the aggregate sample is determined by a color test using a 3 percent sodium hydroxide solution. A specified amount of the sample is placed in a container with the solution, agitated and allowed to stand 24 hours. The color of the liquid is then determined by electric colorimeter and compared with a standard-color solution of tannic acid, alcohol, and sodium hydroxide.

Size and Grading. The determination of the particle-size distribution of aggregates is a standard laboratory procedure which involves the use of sieves. The sample is weighed and run through nested sieves of progressively finer mesh openings, vibrated either mechanically or by hand. The size fraction that accumulates on each sieve is then weighed and the results are reported variously as total percentages passing each sieve, as total percentages retained on each sieve, or as an artificial number called the "fineness modulus". The fineness modulus is obtained by adding the cumulative percentages retained on the #100, 50, 30, 16, 8, 3⅜ inch, 1½ inch, and 3-inch sieves, and dividing by 100.

Specific Gravity and Absorption. Specific gravity and absorption are utilized as a basis for designing concrete mixtures and are also important in determining the quality of the aggregate. The test procedure consists of weighing the water-saturated sample both in air and in water, and again after it has been oven-dried. Absorption and specific gravity are then calculated, using the results of the weighings. Specific gravity is expressed by the ratio of the weight of a given volume of aggregate to the weight

of an equal volume of water. Absorption is expressed as a percent ratio of the weight of moisture absorbed to the dry weight of the material.

Sand Equivalent. The California Division of Highways has recently adopted a test to determine the effective volume of detrimental fine dust or clay-like materials in fine aggregates (California Standard Specifications, 1954, p. 26). The test is performed by shaking, using a prescribed technique, a known volume of the sample in a glass cylinder with a water solution of calcium chloride, glycerine, and formaldehyde. The mixture is permitted to stand 20 minutes and the relative volume of the clay and sand is then measured. The sand equivalent is the ratio of the volume of sand to the volume of clay and is expressed as a whole number. The higher the number the lower the clay content.

Alkali Reactivity Tests. Alkali-aggregate reactivity has been discussed at length in many publications (Goldman, 1959; Merriam, R., 1953). A reactive aggregate is any rock, gravel or sand that contains one or more constituents that react chemically with the alkalies (sodium and potassium) in some types of portland cement. This reaction, which may result in expansion, cracking and deterioration of concrete, arises from osmotic pressures produced by the formation and hydration of alkali silica gels. The gels are formed through interaction between the mineral aggregate and the alkalies which are liberated by the cement during hydration (McConnell et al, 1950, p. 234). Opal (amorphous hydrous silica) is the most widespread aggregate material reacting in this manner. Other rocks and minerals known to be reactive are: glassy volcanic rocks, some chalcedonic rocks, certain phyllites which contain a hydro-mica, and the minerals tridymite, heulandite, and certain other zeolites. Any rock containing a significant proportion of reactive substances may be deleteriously reactive; thus normally non-reactive sandstone, shale, basalt, granite, and other rock types may be harmful if impregnated or coated with opal, chalcedony, or other reactive substances.

There are several approaches to the determination of harmful quantities of chemically reactive impurities in aggregates. Petrographic examination for physical and chemical properties has been mentioned previously. During such examinations the petrographer is alert for the presence of constituents that may be chemically unsound. By using the petrographic microscope one can readily identify reactive ingredients such as opaline silica, chalcedony, and volcanic glass, and estimate the quantity present. On the basis of petrographic observations, aggregates containing suspected reactive materials can be subjected to such substantiating laboratory tests as the mortar bar expansion test and the chemical method of determining potential reactivity.

In the mortar bar expansion test the test aggregate is sieved and mixed with cements of known alkali content to form 1-inch by 1-inch by 10-inch mortar bars. These are cured under laboratory conditions of controlled temperature and humidity for specified lengths of time, usually 1 to 2 years. Periodically the lengths of the bars are measured and the reactivity expressed as the percentage of expansion in a given length of time. The excessive length of time required to perform this test has led to the establishment of a quick chemical test.

The quick chemical test for determining potential reactivity of aggregates is based on the degree of reaction of the aggregate with a sodium hydroxide solution under controlled laboratory test conditions. The procedure as described by Mielenz (McConnell et al., 1950) involves digesting a pulverized sample of the material in a sodium hydrdoxide solution and filtering the mixture. A portion of the filtrate is analyzed to determine the amount of dissolved silica. The alkalinity of the balance of the filtrate is determined chemically by comparison with a solution of known acidity. The amount of dissolved silica and the reduction in alkalinity are used as a measure of the potential reactivity.

General Specifications for Concrete Aggregate

The study of the results of laboratory tests on aggregates that have good service records in concrete has led to the establishment of certain minimum requirements or specifications to which aggregates are expected to conform. These specifications are designed so that completely serviceable concrete will be made, if any aggregate that meets the requirements is used. Most specifications written by government agencies, engineering societies, and concrete technologists attempt to conform to one standard set of specifications—those set up by the American Society for Testing Materials; but modifications of these standards for certain types of concrete work make it difficult to compare individual requirements of the various organizations. Therefore it is a difficult task to evaluate the suitability of a deposit by judging the test results of selected samples. Some deposits which may not meet certain required specifications may have to be utilized because of other outside factors, such as the greater expense of hauling a more suitable aggregate.

In general, aggregate from an untried deposit will be satisfactory for most uses if it meets the following minimum standards (these specifications are a general average of the basic requirements recommended by the ASTM, California Division of Highways, U. S. Army Corps of Engineers, and the U. S. Bureau of Reclamation).

Abrasion—The abrasion loss should be less than 30 percent.

Soundness—The loss in the sodium sulfate test should be less than 10 percent.

Specific Gravity—The specific gravity should be greater than 2.55.

Size and Grading—
  a. The deposit has proper grading so that the fine aggregate should contain no more than 45 percent of the material between two consecutive sieve sizes.
  b. The fineness modulus should be between 2.3 and 3.1.
  c. No more than 5 percent of the material should pass the No. 200 sieve.

Reactivity—A mortar bar containing the aggregate should have an expansion less than 0.10 percent in one year with a 0.8 percent alkali content cement.

Absorption—The absorption should not exceed 3 percent.

Durability—The concrete containing the aggregate should not have a loss in the modulus of elasticity exceeding 50 percent in the freeze-thaw test.

Sand Equivalent—The fine aggregate should have a sand equivalent of not less than 75.